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Game-Based Learning, Gamification in Education and Serious Games

Edited by
Carlos Vaz de Carvalho and Antonio Coelho

Printed Edition of the Special Issue Published in *Computers*

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Editors

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This is a reprint of articles from the Special Issue published online in the open access journal *Computers* (ISSN 2073-431X) (available at: www.mdpi.com/journal/computers/special_issues/Game_Learning_Education_Serious).

For citation purposes, cite each article independently as indicated on the article page online and as indicated below:

LastName, A.A.; LastName, B.B.; LastName, C.C. Article Title. *Journal Name* **Year**, *Volume Number*, Page Range.

ISBN 978-3-0365-3810-5 (Hbk)
ISBN 978-3-0365-3809-9 (PDF)

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About the Editors

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Carlos Vaz de Carvalho is currently a Professor at the Computer Eng. Dep. of the Engineering School of the Porto Polytechnic (ISEP) and he is also the Director of Virtual Campus Lda, an SME dedicated to Technology-Enhanced Learning and Serious Games. Since completing his PhD in 2011 in Technologies and Information Systems, focusing on the use of e-learning in Higher Education, he has been lecturing on more than 20 different courses on Algorithms, Programming, Data Structures, E-Learning and Multimedia. Currently, he is lecturing on Serious Games Design and Multimedia Application Development. He started his research career in 1988 at INESC in the Computer Graphics Group. From 2005 to 2014, he was a Scientific Coordinator of GILT R&D (Games, Interaction and Learning Technologies) and he directed eight PhD and over 50 MSc theses and authored over 200 publications and communications, including more than ten books (as author and editor). He coordinated 16 national and European projects and participated in more than 40 other projects. He worked as an expert for the European Commission and associated agencies in the scope of the Socrates-ODL, Minerva, E-Learning, E-Contents Plus, Lifelong Learning, Eurostars, Horizon Europe and Erasmus+ programmes. He directed the Distance Education Unit of the Porto Polytechnic from 1997 until 2000; from 2001 until 2005 he was the E-Learning Director of ISEP; and he served as Dean of the Computer Eng. Dep. between 2003 and 2005.

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Preface to "Game-Based Learning, Gamification in Education and Serious Games"

Video games have impacted many social and cultural aspects of modern life. They have become one of the predominant forms of entertainment, and they have also managed to be recognized as powerful tools that can lead the player to reach "serious" goals. Serious games, defined precisely as games that have a major goal not for entertainment purposes, try more and more to explore the impact of games and the inherent motivation and immersion of players. Games are endogenous systems, associated with problem-solving activities structured by game mechanics (or game rules). Immersion is a phenomenon experienced by an individual when he/she is in a state of deep mental involvement. Games generate this by involving the player in a narrative, or by challenging him/her continuously. Their use in the education and training areas is probably the most common as there are widespread examples of the use of games for these purposes (which lead to the creation of the game-based learning and game-based training terms, precisely representing games that were designed with specific learning objectives in mind). However, educational contexts can also benefit from the use of game mechanics and principles through gamification processes to reinforce the motivation of learners.

This book presents and discusses current advances in the use of games to enhance the effectiveness and outreach of education, advertising, social awareness, health, public policies, etc. It contributes to the research and understanding of the specific impacts of the different game elements in the player's motivation and immersion and on how the design of a serious game affects his/her cognitive and affective development and how all those aspects are interrelated. This book presents a closer look at game-based learning and the use of game design techniques, mechanics and elements to gamify the learning process, but also provides examples of the use of games for other purposes. The published contributions really demonstrate the wide scope of application of game-based approaches in terms of purposes, target groups, technologies and domains and evidence of how effective serious games, game-based learning and gamification can be. The current publication was created for researchers, academics and practitioners in these areas, which includes teachers that may be interested in using the provided cases in their own teaching practices.

Carlos Vaz de Carvalho and Antonio Coelho
Editors

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Editorial

Game-Based Learning, Gamification in Education and Serious Games

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Citation: de Carvalho, C.V.; Coelho, A. Game-Based Learning, Gamification in Education and Serious Games. *Computers* **2022**, *11*, 36. https://doi.org/10.3390/computers11030036

Received: 1 March 2022
Accepted: 2 March 2022
Published: 4 March 2022

Video games have become one of the predominant forms of entertainment in our society, but they have also impacted many other of its social and cultural aspects. The new forms of interaction and communication in online multiplayer games, the millions of viewers of professional e-sports competitions, the huge following of gaming streamers through channels such as Twitch, and the communities of players that are formed around a specific title are just some examples of the impact of games in everyday life today.

However, games are just one aspect of the ludification of culture [1]. Approaches to this field can be situated into the "Game" or the "Play" categories. Although these words are generally presented as entwined in the discourse on video games, they are two distinct subjects. "Game" comes from the Latin word "Ludus", meaning both learning and entertainment. Games are thus associated with problem-solving activities that are fun, and are endogenous systems that are structured by game mechanics (or game rules). On the other side, "Play" comes from the Latin word "Paidia", meaning (childish) amusement, and relates to creativity, freedom to improvise, and in general occurs in open systems. Immersion is a phenomenon experienced by an individual when they are in a state of deep mental involvement [2]. This phenomenon can improve the learning process, and games are able to provide this by involving the player in a narrative, or by challenging the player [2]. These intrinsic properties of games can be enhanced by the multisensory stimulation provided through immersive technology, such as the HDMs (Head-Mounted Displays) used in virtual reality.

Serious games try more and more to explore the impact of games and the inherent motivation and immersion of players to help them accomplish other objectives, be they related to education, marketing, social awareness, health and care, etc. Education is an area with more (successful) examples of the utilization of serious games (therefore leading to the game-based learning term, which focuses on the development of games that are designed with specific learning objectives in mind). Educational contexts can also benefit from the use of game mechanics and principles through gamification processes to reinforce the motivation of learners.

The aim of this Special Issue is to present and discuss new advances in games to show how they could enhance the effectiveness and outreach of education, advertising, social awareness, health, policies, etc. We focus on the "Ludus" side, more related to structured learning activities, not only with a focus on game-based learning and serious games, but also on the use of game elements and game design techniques to gamify the learning process [1].

The published contributions really demonstrate the wide scope of application of game-based approaches in terms of purposes, target groups, technologies and domains. However, one aspect they have in common is that they provide evidence of how effective serious games, game-based learning and gamification can be.

Zafeiropoulou et al. [3] present the design and development of an Augmented Reality (AR) gamified application for the implementation of physics experiments in a fifth-grade class of a Greek primary school. A treasure hunt game was implemented, which allowed students to interact with a digital world and to manipulate virtual objects with the use of an AR device. The evaluation of the system's usability by both students and teachers indicates that the application has the potential to be an easy-to-use educational tool for improving not only the teaching of physics experiments in primary school, but also the learning process, by positively affecting the students' motivation and engagement.

Cheng and Chen [4] present Swift Playgrounds, an innovative app for the iPad and Mac that makes learning interactive and fun. Their study was carried out by letting elementary school teachers and students participate in Swift Playgrounds computational thinking courses. By trying this app, teachers of different disciplines attempted to realize more learning situations. Students learned how to cope with functions and loop skills by playing with "Byte", which is a character in Swift Playgrounds. The authors had three main purposes for the study: first, designing a computational thinking course, "Hello! Byte", in Swift Playgrounds; second, assigning elementary school teachers to assess the qualitative analysis of tasks in Swift Playgrounds; and third, assigning elementary school students to complete the tasks and assign a difficulty index in Swift Playgrounds after using the app. The results show that most teachers considered this approach to be able to improve logical thinking and inferential capability after assessing, and most students considered functions and loops to be quite difficult after using the app. According to the students' indices, about 86 percent of students thought that adding commands is easy, and about 37 percent of students considered the functions to be easy.

Leonardou et al. [5] present the main findings of an online study on primary school teachers' attitudes toward digital game-based learning (DGBL), given the central role teachers play in the learning process. Furthermore, this research investigates teachers' opinions about the functionalities provided by one exemplary case, the Multiplication Game (MG), and the integrated teacher dashboard. The MG is an assessment and skills improvement tool that integrates an adaptation mechanism that identifies student weaknesses on multiplication tables and, in its latest version, also supports a strong social parameter. Students can be informed about their own progress as well as the progress of their peers in an effort to examine if social interaction or competition can increase players' motivation, which is a subject that raised some concerns in the teaching community. The article indicated the potential usefulness of MG and the benefits it can offer as a learning tool to improve pupils' multiplication skills and help teachers identify individual pupils' skills and difficulties and adapt their teaching accordingly.

Arner, McCarthy and McNamara [6] present StairStepper, an adaptive literacy skill training game within an Interactive Strategy Training for Active Reading and Thinking (iSTART) intelligent tutoring system. StairStepper models text passages and multiple-choice questions of high-stakes assessments, iteratively supporting skill acquisition through self-explanation prompts and scaffolding, adaptive feedback based on performance, and self-explanations. The results of an experimental study employing a delayed-treatment control design to evaluate users' perceptions of the StairStepper game and its influence on reading comprehension scores indicate that participants enjoyed the visual aspects of the game environment, wanted to perform well, and considered the game feedback helpful. The results also indicate that the StairStepper game may fill the gap in instruction by providing enjoyable practice of essential reading comprehension skills and test preparation, potentially increasing students' practice persistence while decreasing teachers' workloads.

Santos et al. [7] presented the League of Emotions Learners (LoEL) game app, designed to develop the emotional competence and intelligence of young people. The authors stress the importance of being able to understand, express, and communicate emotions, a competence widely recognized as fundamental. This is particularly important for the younger generation entering the professional market as, in this context, emotions are managed and communicated in ways that are different from what they are used to and that can easily lead to misunderstandings. The game app was designed following an analysis on how young people deal with, understand, and interpret emotions, particularly in the context of a professional career, where the ability to enter a dialogue with different people and how to get around problems in a healthy and resilient way is essential. The results obtained in the initial validation show a very positive understanding of the impact of this app on youth.

Maskeliūnas et al. [8] describe an interactive serious programming game for teaching JavaScript programming in an introductory course at university. The game is based on visualizations of different types of algorithms, which are interpreted in the context of city life. This game encourages interactivity and pursues a deeper learning of programming concepts. The positive results of the evaluation of the game using pre-test and post-test knowledge assessment are presented.

Riera et al. [9] present a work that uses a Virtual Reality (VR)-enhanced gamified application designed to increase the awareness of safety measures, one of the most important being the correct usage of the seat belt, a device that is known to save thousands of lives every year. For this goal, a motorized rollover system was developed that, synchronized with a VR application shown in a head-mounted display for each user inside a real car, simulates the rolling of the car with up to four passengers inside. This way, users feel the sensations of a real overturn and therefore they realize the consequences of not wearing a seat belt. The system was tested by more than 500 users, for a month, in the context of a road safety exhibition in Dammam, Saudi Arabia. The results show that awareness regarding the use of seat belts increased very significantly after using the presented edutainment tool.

Heldal et al. [10] investigated the feasibility of utilizing serious games (SGs) and eye-tracking technologies (ETs) for training the eyes of children with oculomotor dysfunction (OMD), a condition resulting from problematic coordination between their left and right eye muscles. Via the activities they created, a trainee can, with their eye gaze, follow objects that are moving, change their directions and speed, or pop up on the screen. The results map the current physical training goals to activities for SGs using the input from ETs, and illustrate this correspondence for designing and developing six games. The games' feasibility evaluation was conducted via semi-structured interviews and evaluations of user experiences; the findings demonstrate the potential of using SGs and ETs to train OMD and point to future needs for improvements.

Tuah, Yoag and Ahmedy [11] report on the development of a gamified application with several tasks aimed at managing diabetes mellitus as these are regarded as useful for patients in facilitating daily self-care management and the personalization of health monitoring. The developed application was tested through system testing and usability testing using the Software Usability Scale (SUS). The result showed that the gamified application is easy and practical to use for an individual with or without diabetes. All the provided functions worked as designed and planned, and the participants accepted their usability.

Sipiyaruk et al. [12] present an integrative review that explores the literature on serious games in dental education to construct a conceptual framework. Their investigation demonstrated an increase in the use of serious games since 2018 and the key strengths of the findings include positive educational outcomes, enhanced engagement and motivation, and the advantage of stealth assessment.

Funding: This research received no external funding.

Conflicts of Interest: The author declares no conflict of interest.

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Article

Developing Physics Experiments Using Augmented Reality Game-Based Learning Approach: A Pilot Study in Primary School

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Abstract: The augmented reality game-based learning (ARGBL) approach is an advantageous pathway for the development and enhancement of teaching and learning processes. To this end, this paper presents the design and development of an ARGBL application for the implementation of physics experiments in the fifth grade of a Greek primary school. The purpose of the ARGBL system is twofold: to educate and entertain. For this reason, a treasure hunt game was implemented, which allows students to interact with a digital world and to manipulate virtual objects with the use of an augmented reality (AR) device. Then, according to the instructions, students have to collect all the materials to conduct the AR educational experiment. Overall, the evaluation of the system's usability by 17 users (both students and teachers) was very promising, indicating that the ARGBL application has the potential to be an easy-to-use educational tool for improving not only the teaching of physics experiments in primary school but also the learning process, by positively affecting the students' motivation and engagement.

Keywords: augmented reality; game-based learning; usability; primary school; physics

Citation: Zafeiropoulou, M.; Volioti, C.; Keramopoulos, E.; Sapounidis, T. Developing Physics Experiments Using Augmented Reality Game-Based Learning Approach: A Pilot Study in Primary School. *Computers* **2021**, *10*, 126. https://doi.org/10.3390/computers10100126

Academic Editors: Carlos Vaz de Carvalho and Antonio Coelho

Received: 9 September 2021
Accepted: 7 October 2021
Published: 11 October 2021

1. Introduction

Azuma [1] defined augmented reality (AR) as a technology by which users can integrate 3D virtual objects in real time into their real-world environment. AR is a popular technology that is used in many aspects of our lives [2,3]. The basic reason for its popularity is that it has no special equipment requirements as in virtual reality. A smart device (tablet or smartphone) is enough. Moreover, recently, large companies in the field of information technology, such as Google and Apple, have delivered suitable frameworks and APIs to programmers, in order to develop a high quality of augmented reality applications, such as ARCore [4], ARKIT [5] and libraries for Unity [6].

For the last decade, augmented reality has been used in research to improve the educational process at all levels of education from primary education to university [7]. A remarkable number of augmented reality applications have been created, which basically augment the content of a schoolbook mainly using text, pictures and video [8,9]. Field experiments using AR application in education have shown that the education process was improved by increasing the fun, enjoyment, interest and engagement of students [7]. Furthermore, another interesting approach that has gained attention in education science is augmented reality game-based learning (ARGBL), which can transform the learning experience and influence students' motivation, skill development and knowledge [10]. Apart from the learning process, AR and ARGBL technology can additionally benefit the teaching process. Teachers who integrate such innovative approaches into the teaching process can introduce and explain to students complex and/or abstract concepts through a multisensory way, encouraging social interaction and improving collaboration [7,11]. All in all, AR and ARGBL can be successfully used in educational environments, positively affecting both the teaching and the learning process, since (a) the cost of materials for the experiment disappears (sometimes a big problem for the education procedure [11]), (b) the experiment can be repeated as many times as the educational process requires (without the thought of wasting materials) and, most importantly, (c) the student can repeat the experiment when studying the course at home.

In this paper, an ARGBL approach was introduced for teaching the experimental part of a lesson of physics in the fifth grade of a Greek primary school. In particular, an application is presented that is based on ARGBL for the development of all the experiments for the unit of physics in the fifth grade of a Greek primary school. The contribution of this research is multifaceted. The case study focuses on lab/practical experiments in a unit such as physics, by adopting a game-based approach, which, according to the literature review, has found limited implementation in primary schools. All the experiments can be executed using an ordinary smart device such as a smartphone or a tablet. Additionally, the applications were designed to be interactive. This was conducted using game-based learning, where students are invited with a treasure hunt game to discover the materials of the experiment in one place. Thus, they are "forced" to pay attention to the materials used for the experiment. Then, after "accomplishing the mission" of finding all the materials, they can "run" the experiment as many times as they want until all the questions regarding the experiment and the physics topic are answered. We used the ARGBL application to perform a pilot experiment in a primary school, where the results were very satisfactory and showed that this approach greatly improves the educational process as it increases the fun, enjoyment, engagement and interest in the course.

This paper is organized as follows. In Section 2, AR and ARGBL are introduced. In Section 3, a short review is presented regarding the use of AR and ARGBL in physical science in both primary and secondary school. Next, in Section 4, the description of the suite of applications is analyzed, and in Section 5, the pilot experiment and its results are presented. In Section 6, the discussion of the research work is analyzed, and finally, in Section 7, the conclusions as well as future work are presented.

2. Augmented Reality Game-Based Learning

AR is an emerging technology, which has great potential. Although the first AR applications appeared in the late 1960s [12], it has become more pervasive and affordable in recent years due to the widespread use of mobile devices [13]. AR essentially blends virtual worlds into real ones, by allowing the user to explore, manipulate and interact in a seamless way with both digital and natural objects in real time [14,15]. Additionally, it allows them to envision objects in different situations and receive immediate visual feedback about their actions in a totally safe environment [12]. Therefore, AR improves learners' ability to understand abstract and complex concepts [16], since it can provide enriched experiential and in situ learning experiences [12].

Another learning approach that takes advantage of experiential learning theory is game-based learning (GBL), which uses specially designed games to improve the learning process [17]. One of the advantages of GBL is that through games, users construct their own knowledge and develop the ability to transfer it to other contexts, rather than passively absorbing a new concept, a pillar that the traditional educational process supports [18]. Therefore, of particular relevance to the education sector are the two aforementioned pedagogical approaches which both enhance the learning experience and learners' effectiveness by actively engaging them.

The term ARGBL, which is basically the integration of AR into GBL, is gaining more and more pace nowadays. According to Pellas et al.'s [19] systematic review, some of the most popular domains of ARGBL use in primary and secondary school education are formal science [20–23], natural science [24–27], physical science [15,28–31] and social science [32–34]. Additionally, problem solving, performance, motivation, satisfaction, creativity and collaboration [33] are, among others, benefits of ARGBL in the learning experience.

3. Review

Several previous studies have been conducted to explore the use, benefits and limitations or challenges of AR and ARGBL at all levels of education in the domain of physical science (such as physics, astronomy and chemistry). More specifically, Enyedy et al. [15] developed an AR environment to teach Newtonian force and motion to young children, 6–8 years old. During the activity, children had to predict how the forces would influence the motion of an object (e.g., ball). The results showed that children made significant progress in learning the content and improved their performance, since they engaged, explored and reconstructed their conceptual knowledge through fruitful confrontation and discussion. Additionally, Cai et al. [28] conducted a convex imaging experiment using AR technology, in which the eighth graders explored basic concepts of physics (such as image distance and focal distance) as well as abstract ones (such as what will happen when the object moves closer to the lens). The findings revealed that the AR tool attracted their attention, stimulated their interest and enhanced their learning. A few years later, Cai et al. [29] implemented a system that integrates AR with natural interaction technology by using Kinect, in teaching magnetic fields to students in grade 8. Students could trigger the magnetic field in real time with a wave of their hand in front of the depth camera. The experimental results stated that the system encouraged participants to learn more extensively through a more intuitive way, by activating their motivation and interest in learning.

Regarding astronomy, Zhang et al. [30] designed an AR-based mobile digital armillary sphere for astronomy. An intervention was organized for fifth grade elementary school students, and the purpose was to examine if they could properly identify the constellations through astronomical observation. The analysis indicated that the observation tool, which is based on kinesthetic-style strategies, positively affected participants' motivation and engagement as well as improving their learning experience and observation skills.

Finally, Cai et al. [31] proposed an AR simulation system in which students could control particles in micro-worlds and compose substances. This study was conducted in a junior high school for the chemistry course. Through data analysis, the authors concluded that the AR tool improved the learning outcome and helped students to develop different skills such as problem solving and inquiry-based exploration skills.

Leveraging the aforementioned studies, AR and ARGBL have proved to be advantageous in enhancing performance and learning experiences, developing skills (e.g., problem solving, inquiry-based exploration, observation) and fostering motivation, engagement, attention and interest. Moreover, through AR, students can learn and interact with virtual and real objects in a more intuitive way. Therefore, teachers should integrate such innovative applications which place emphasis on the design of more natural and realistic representations of complicated problems of everyday life into the educational process. However, AR and ARGBL pose some limitations and challenges. Due to the technologies' novelty, proper training and guidance should be provided to both students and teachers [29]. In addition, according to Tobar-Muñoz et al. [35], sometimes there is a gap between designers and teachers in conceiving learning. It is thus important to involve both designers and teachers in the design and development of such AR tools, in order to create a proper learning experience in the classroom that would be only beneficial.

4. Application Description

An ARGBL application for the physics course of the fifth grade in a primary school was developed and evaluated in the present paper. The application follows the new technological developments of smart mobile devices and introduces the concept of AR to the students. Since the purpose of the ARGBL application is both to educate and entertain, a treasure hunt game was implemented, which allows students to interact with a digital world and to manipulate virtual objects with the use of an AR device. They have to discover all the materials in order to conduct the AR experiment, according to the instructions that correspond to each experiment.

4.1. System Overview

In this section, the system overview of the ARGBL application is presented. The system consists of the following components: (a) a smartphone device (hardware), and (b) the Unity platform (software), as shown in Figure 1. More analytically, the ARGBL application was implemented using the free version of the Unity game engine and C# as the programming language. The Unity platform was chosen because Unity software is powerful, easy to use and free [36]. Vuforia SDK was also used to ensure a better AR experience. At first, Unity sends the virtual content to the ARGBL application. Then, the input device, which is the camera of the smartphone, scans the QR code of the textbook and sends the real content to the ARGBL application. Subsequently, the ARGBL application processes the virtual and the real contents and finally displays the augmented content through the smartphone screen, which is the display device.

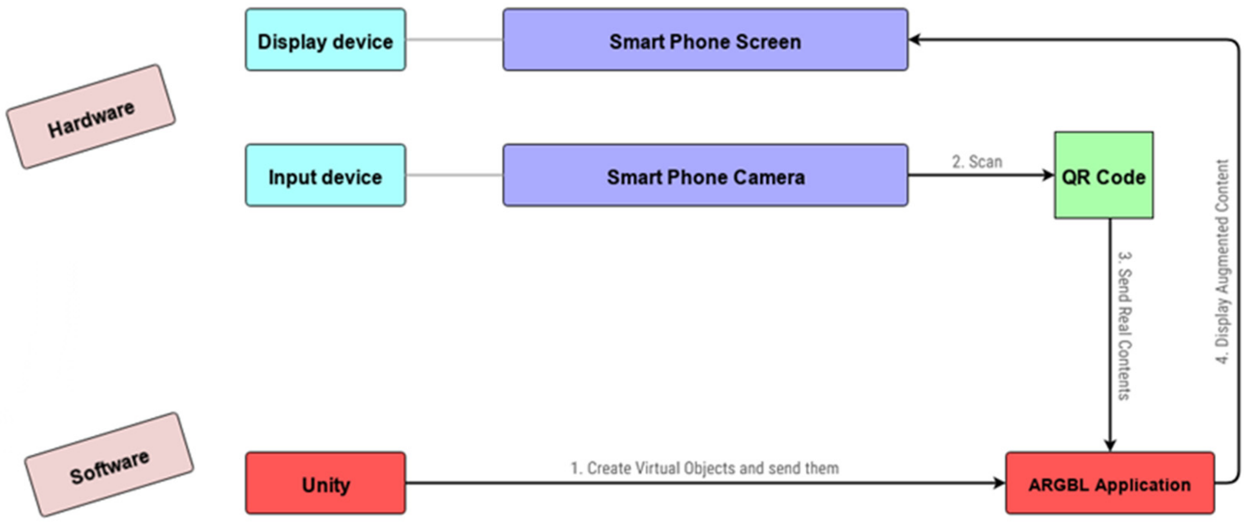


Figure 1. Application components.

In Unity, there is a set of elements which together form a game. These elements play a major role in making the game interactive as well as adding features that can vividly express the objective of the game. The proposed ARGBL application includes the following elements: 41 scenes, 88 scripts, 17 packages, hundreds of assets and thousands of 3D gameobjects and prefabs.

4.2. Suite of Applications

The suite of applications is a collection of six experiments, where each experiment corresponds to one of the six chapters of the fifth grade textbook. According to the curriculum of the 2019–2020 school year, the chapters are: (a) material bodies, (b) energy, (c) digestive system, (d) heat, (e) electricity and (f) light. More analytically, on the start screen (Scene 1), there are six buttons which correspond to the chapters of the book (Figure 2). By selecting a chapter, the application sends the user to the next scene (Scene 2), which is composed of the available experiment.

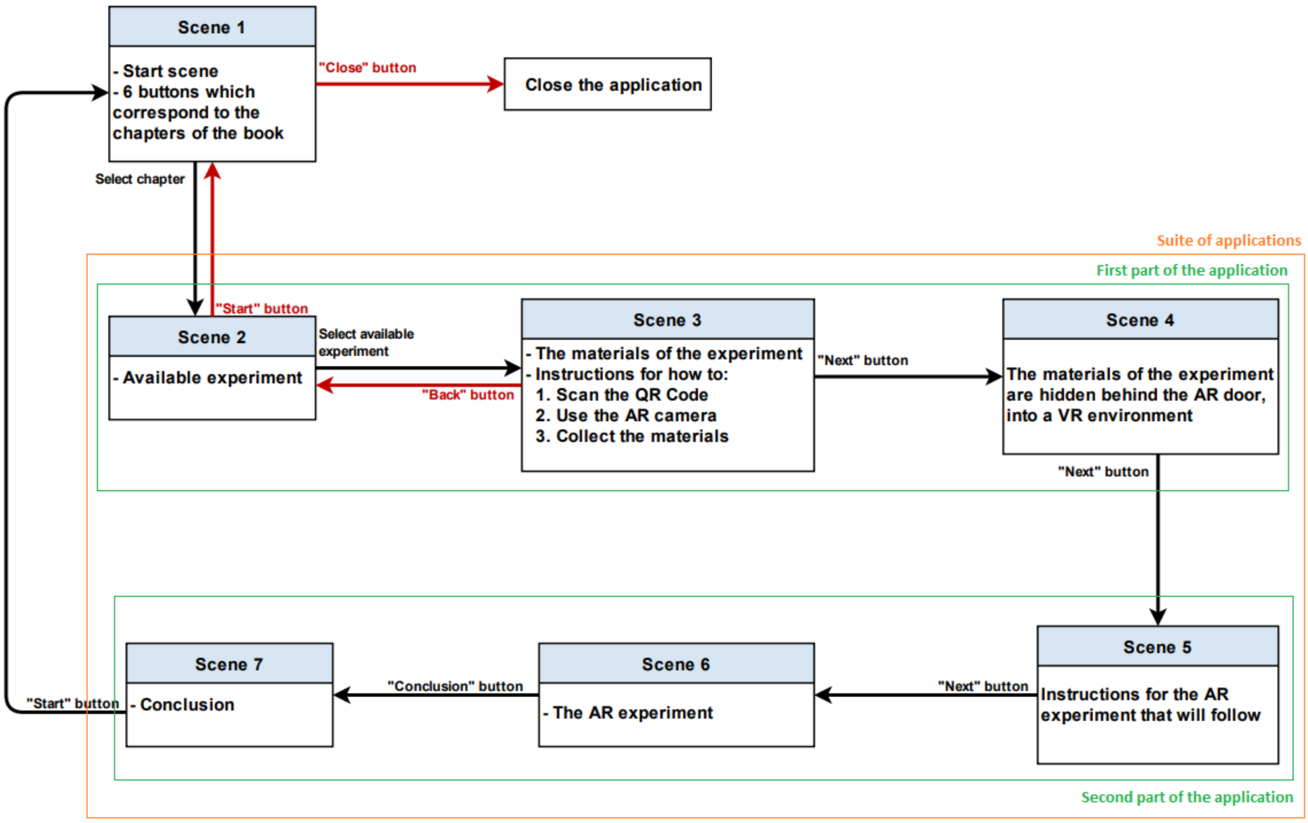


Figure 2. Application sub-components.

According to the student's choice, instructions are displayed (Scene 3) about how the experiment will be performed using the AR technology. In the next scene (Scene 4), the camera of the user's device is activated, and by scanning the QR code of the textbook page where the experiment is located, an AR door appears. Entering the door, the user is immersed into a VR environment. There are hidden virtual objects that must be collected in order for the educational experiment to be implemented, by using AR. At the bottom of the screen, there is a list with all the materials of the experiment which are hidden behind the AR door. In order for the user to proceed with the experiment, they must first collect all the materials by clicking on them in the VR world. Then, the materials are automatically checked in the list. It is basically a treasure hunt game, representing the first part of the ARGBL application which is for entertainment purposes.

Once the student has collected all the necessary materials for the experiment, instructions for the experiment that will be followed are displayed (Scene 5). After scanning the QR code of the textbook page for the selected chapter again, the available experiment is displayed (Scene 6). The available experiments are performed differently by the user, meaning that each experiment has a different process, instructions and learning outcomes. Moreover, with the teacher's guidance, a fruitful discussion takes place in order for students to draw a conclusion. At the bottom of the screen, there is the "conclusion" button which leads the student to the next and the last screen (Scene 7), which consists of the conclusion. This represents the second part of the application which is for educational purposes.

4.2.1. Experiments

As already mentioned, six (6) experiments were formulated, and each one consists of Scenes 2–7 (Figure 2). Scenes 2, 3, 5 and 7 are almost the same in all experiments, with minor changes in their content. The scenes that differ are Scene 4 and Scene 6. Table 1 analytically describes the process of each experiment.

Table 1. Process of each experiment.

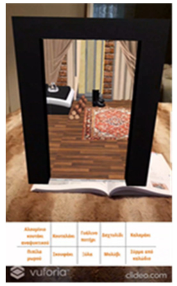
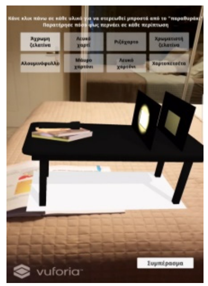
Scene \ No	#1 Section: Material Bodies—Mass	#2 Section: Energy	#3 Section: Digestive System—The Food Journey	#4 Section: Heat—Temperature and Heat	#5 Section: Electricity—Conductors and Insulators	#6 Section: Light—Transparent, Semi-Transparent and Non-Transparent Bodies
Scene 4: QR Code	AR door and VR room representing a patisserie shop 	AR door and VR room that is a warehouse 	AR door and VR room that looks like a living room 	AR door and VR room that is a living room 	AR door and VR room that represents a bedroom 	AR door and VR room that looks like a corporate office 
Scene 6, step 1: AR experiment	(a) AR table with all the products; (b) 8 buttons corresponding to the 8 product combinations; and (c) “conclusion” button 	(a) AR circuit; (b) 2 buttons corresponding to the two modes (Connect/Disconnect); and (c) “conclusion” button 	(a) AR table with all the products is displayed; (b) once the experiment is completed, the “conclusion” button appears 	(a) AR electric stove with a water pot and a thermometer; (b) start button (5 min count starts); (c) “conclusion” button (appears after 5 min) 	(a) AR circuit; (b) 10 buttons corresponding to the 10 materials; (c) “conclusion” button 	(a) AR table with a torch emitting light and a cardboard window; (b) 8 buttons corresponding to the8 materials that must be placed in the cardboard window; (c) “conclusion” button 

Table 1. *Cont.*

Scene \ No	#1 Section: Material Bodies—Mass	#2 Section: Energy	#3 Section: Digestive System—The Food Journey	#4 Section: Heat—Temperature and Heat	#5 Section: Electricity—Conductors and Insulators	#6 Section: Light—Transparent, Semi-Transparent and Non-Transparent Bodies
Scene 6, step 2: Interaction	Find 3 of the 8 combinations with which the scale is balanced	Interact with the AR circuit and observe the light bulb in both situations	Click on the materials in the correct order to perform the experiment	Measure the temperature every minute for 5 min	Select each one of the materials and observe the behavior of the light (if the light is on or not)	Click on any material, put it between the torch and the cardboard window and notice how much light passes through
Scene 6, step 3: Conclusion	*"Mass is a characteristic property of all bodies. When the masses on the scale are equal, then the scale is balanced."*	*"The light does not illuminate when the battery is disconnected from the circuit."*	*"Liquid dish soap dissolves oil, as saliva helps break down food starch and bile dissolves fats during digestion."*	*"Part of the energy is released when the gas burns. This part of the energy is absorbed by the water. Therefore, the water temperature rises."*	*"The materials are classified into conductors (if the light is on) and insulators (if the light is off)."*	*"Material bodies are characterized as transparent, semi-transparent and non-transparent, depending on the amount of light they allow to penetrate."*

Two Indicative Examples

In this section, two indicative examples of the experiments are presented. Firstly, the example of the "Electricity" experiment which belongs to the section of "Conductors and Insulators" is described. This section begins with an introductory stimulus and is followed by an experimental approach. More analytically, the introductory stimulus is presented through a school textbook comic, where "Lampakis" and "Volfraimios" (Tungsten) are the main characters. The following information is provided to the students: the material of which the wire in incandescent bulbs is made is called tungsten. Then, the students are asked to read the dialogues in the comic, in order to describe the problem that Lampakis and Volfraimios are faced with. The problem is that the light bulb of the circuit they made by using a rope instead of a cable does not light up. At the end of the introductory stimulus, the teacher helps the students to make assumptions about possible materials that can be used in a closed electrical circuit, in order to light the bulb.

The experimental approach that follows helps students find out that while some materials allow electricity to flow, others do not. The materials of the experiment appear through some virtual objects, as shown in Table 2.

Table 2. Objects and the materials they are made of for the "Electricity" experiment.

Object	Material
Aluminum refreshment can	Aluminum
Spoon	Steel
Glass	Glass
Ring	Silver
Straw	Plastic
Baby's dummy	Rubber
Beanie	Cloth
Wood	Wood
Pencil	Graphite
Wires	Copper

The AR experiment is carried out with the guidance of the book and the teacher. At first, an electrical circuit is displayed above the QR code of the textbook, using the technology of AR. In addition, at the top of the screen, there are ten buttons that correspond to the ten materials/objects of the experiment. By selecting each button, the corresponding object is placed between the connectors of the electrical circuit. The student, after observing the behavior of the light, notes down the materials with which the light can be turned on or not in the provided table of the textbook. The teacher leads a discussion in the class, through which the students will formulate the conclusion. The teacher also introduces the terms of "conductor" and "insulator" and explains them to the students. The teacher then urges them to classify the materials studied in the above experiment into conductors and insulators. Finally, the following conclusion is drawn in the school textbook:

- Conductors: aluminum foil, steel, silver, graphite and copper.
- Insulators: glass, plastic, rubber, cloth and wood.

At the bottom of the screen, there is a "conclusion" button, which leads to the next screen which consists of the conclusion of the experiment, for the students to check the correctness of their answers. After completing the above experiment, the learning objectives that are desired to be achieved by the students are to experimentally establish the existence of conducting and non-conducting materials and to understand the concepts of conductors and insulators.

Another indicative example, which is the experiment of the "Digestive system" experiment which belongs to the section of "The food journey", is presented. Similar to the previous example, it includes two parts, the stimulus and the experiment. In the introductory stimulus, the students are asked to chew bread. Then, it is explained by the teacher that bread contains a substance called starch, and it is stated that saliva breaks down food starch. The following experiment helps the students to understand the above introductory stimulus, by drawing a parallel between saliva (which breaks down starch) and liquid dish soap (which breaks down oil).

At first, a table in which all the materials of the experiment are placed is displayed above the QR code of the textbook, using the technology of AR. The goal of the experiment is that the student, after carefully reading the instructions provided by the textbook, has to "click" on the materials placed in the AR table in the correct order. At the top of the screen, there is a text prompting the student to "Click on the materials in the correct order to perform the experiment". The correct order, according to the presentation of the textbook, is: water, oil, straw, liquid dish soap and straw. The experiment consists of the steps shown in Table 3. At first, a glass is filled halfway with water, and then a few drops of oil are added. The students have to mix the solution well with the straw. They should also notice that the oil does not dissolve in the water, but floats on it. In the second phase of the experiment, a small amount of liquid soap is poured into the glass with water and oil, and after mixing well with the straw, it should be observed by the students that after adding the dishwashing liquid, the oil dissolves and mixes with the water. Finally, the students learn the usefulness of saliva for the dissolution of food starch and the usefulness of bile in the function of digestion.

Table 3. The experiment for "Digestive system" step by step.

No. of Step	Click on	Action
#1	Water bottle	Put water into the glass
#2	Oil	Put oil into the glass
#3	Straw	Stir the mixture
#4	Dish soap	Put liquid into the glass
#5	Straw	Stir the mixture

The conclusion is established with appropriate questions and discussion in class. Students should be aware that the effect of liquid dish soap on oil is the same as the effect of bile on food fats. Finally, students are asked to formulate the following conclusion: "Liquid dish soap dissolves oil, as saliva helps break down food starch and bile dissolves fats during digestion". Once step 5 is completed, the "conclusion" button appears at the bottom of the screen, which leads to the screen with the final conclusion. Moreover, students can check if their answers are correct.

All the experiments are available online (Part 1: https://www.youtube.com/watch?v=0ST0fkDIFEY, accessed 6 August 2021 and Part 2: https://www.youtube.com/watch?v=8jnbmKPim5U, accessed 6 August 2021).

5. Pilot Experiment

The pilot experiment was conducted through a combination of qualitative and quantitative methods. An unstructured interview along with participant observation was carried out to gather qualitative data. This combination of methods aimed to gain insight about the experience of both students and teachers. Regarding the quantitative method, a questionnaire was administered to all participants aiming to evaluate the system's usability. For the system's usability, we used the system usability scale (SUS) which was developed by Brooke [37] as a quick and dirty survey to evaluate the usability of a given system. The SUS test was used because (a) it provides a single score, (b) it is technology-independent and this makes it quite flexible for the system we had to evaluate, (c) it is easy to handle, (d) the questionnaire is nonproprietary and this makes it cost-effective, (e) it is highly effective in terms of reliability [38] and validity [39], (f) it is translated in Greek [40] and (g) it provides reliable results even with a small sample size [39].

5.1. Participants

The study took place at an Elementary School of, Thessaloniki, Greece, during the winter period (January 2021). Fourteen (14) students and three (3) teachers participated in the study. The average age of the students was 10 years. The three teachers who took part in the experiment process had extensive teaching experience (more than 10 years).

All students and teachers volunteered to participate in the activity as part of their everyday school activities. Before the experiment took place, there was a training session with the teachers of the classroom about the implementation of the experiment. The experiment was part of the current school curriculum so that the flow of the school curriculum would not be disturbed, and it was performed within the class hour (duration of 45 min). The students were randomly assigned to work in dyads, forming seven (7) student groups in total, while teachers participated as instructors.

5.2. Setting

Experiments were conducted in classrooms that were offered by schools for this purpose. The classrooms were adequately arranged so that the system was accessible for all students. The system was projected on the whiteboard of the classroom, by the instructor, to be visible to everyone. Additionally, the system was provided to each student group through a smart mobile device.

5.3. Material and Procedure

Students, their parents and teachers were informed about the pilot study one week before the experiment. The lesson was started with an introductory stimulus related to the experiment by the teacher/instructor. Then, the instructor provided instructions and guidelines to the students on how to use the system. The execution steps of the experiment were displayed simultaneously on both the whiteboard of the classroom through the projector, and the screen of the mobile of each dyad of students.

Data were collected through an unstructured interview, participant observation and a questionnaire. Specifically, during the experiment, participants were observed regarding how they react and behave. At the end of the experiment, questionnaires were distributed to both students and teachers in printed form and were answered individually. The completion of the questionnaires was conducted in the same classroom, always in visual contact with the system. After that, an unstructured interview was carried out with the three (3) teachers.

The collected data from questionnaires were organized in Microsoft Excel 2019 and were analyzed using IBM SPSS Statistics v23.0. The system usability scale (SUS) test was translated in Greek and was administered to the students in printed form after the interaction with the system.

6. Results and Discussion

6.1. Evaluation of Quantitative Method

The data collected from the questionnaires in the pilot, along with the mean values and standard deviations for the students and teachers in each question, are presented in Table 4. The overall SUS score was 84.642 (sd 5.773) for the students, while the score for the teachers was 78.333 (sd 10.735). In both cases, the score is quite satisfactory and shows that the system was quite usable for both students and teachers.

Table 4. Mean values and standard deviations of students' and teachers' responses.

Item	English Version of SUS	Student Responses Mean (Std)	Teacher Responses Mean (Std)
Q1	I think that I would like to use this system frequently	4.071 (0.997)	4.6667 (0.577)
Q2	I found the system unnecessarily complex	1.285 (0.611)	1.6667 (0.577)
Q3	I thought the system was easy to use	4.5 (0.854)	4.0000 (0.000)
Q4	I think that I would need the support of a technical person to be able to use this system	1.785 (1.050)	2.3333 (1.527)
Q5	I found the various functions in this system were well integrated	4.571 (0.646)	4.0000 (0.000)
Q6	I thought there was too much inconsistency in this system	1.785 (1.050)	2.3333 (0.577)
Q7	I would imagine that most people would learn to use this system very quickly	4.714 (0.468)	4.3333 (0.577)
Q8	I found the system very cumbersome to use	1.357 (0.497)	1.6667 (0.577)
Q9	I felt very confident using the system.	4.428 (0.755)	4.0000 (1.000)
Q10	I needed to learn a lot of things before I could get going with this system.	2.214 (1.476)	2.3333 (0.577)

More analytically, the average SUS score of the ARGBL application is acceptable for teachers (over 75), while the score for students is relatively high (84.642). This could be explained by the fact that the system worked properly. Although the experiment was successful for both students and teachers, there was a concern about how the students would manage to use the system to conduct the physics experiment. The fact that students are familiar with such devices along with the daily usage of them made it easier for them to handle the device and successfully complete the experiment. However, this led the students to ask questions about the process of the experiment, e.g., how to collect the experiments' materials from the VR room. Although there were written instructions on the screen, students were overwhelmed by the virtual world and, as a result, did not read them. A possible solution to this could be the use of tablets, since the instructions on bigger screens might easily be "caught by the eye".

6.2. Evaluation of Qualitative Method

Based on the observation data, we noticed that most of the students had the curiosity to try new activities, including conducting experiments using the AR technology through smart devices. Therefore, teachers should try innovative instructional methods, tailored to new requirements relating to the ARGBL application. It is worth mentioning that teachers should conduct a training session for students about how to use the system and how to interact with the QR code, before the experiment takes place. In addition, the performance of QR code recognition is mainly based on lighting conditions. The virtual objects formed under weak light conditions may twinkle at times. As a result, teachers are required to adapt the classroom properly in terms of lighting.

According to the unstructured interview with the teachers about their experience, they supported that the group of two students rather than larger groups is more preferable. It was also mentioned that small groups (two or three students) work better than larger groups, not only in the collaboration between the team members but also in the time that the system is used by each member, a fact that positively triggers students' motivation, engagement and teamwork. Nonetheless, groups of two students would require a lot of equipment (number of smart devices), in the case of a larger sample. Last but not least, the teachers agreed on the fact that the ARGBL application is more advantageous, since it can run offline, without the need of an internet connection. This makes it a lot easier to be used in areas of limited WiFi or data connectivity, such as schools. The students can use the ARGBL application instantly without any delays or internet difficulties. On the other hand, applications that work offline do not provide the functionality of interaction to users. In the ARGBL application, the interaction between users is conducted face to face in a classroom. This means that a discussion between the students as well as between the teacher and the students is necessary to evolve the learning process.

7. Conclusions and Future Work

Leveraging the aforementioned findings, an ARGBL application was proposed for the implementation of physics experiments in the fifth grade of a Greek primary school. The application is both educational and entertaining, since the students have to conduct a physics experiment by playing an AR treasure hunt game. A pilot experiment was conducted, and a questionnaire was administered to all participants, both students and teachers, in order to investigate the usability of the system. Moreover, this study explored the opinions and the preferences of the participants by the process of unstructured interviews and observations. The results of the pilot experiment are very promising, since the system's usability was satisfactory, revealing that the proposed ARGBL application can provide added value to the educational community. More specifically, what we learned, which is in accordance with the literature review, is that students had a positive attitude towards using the system for their learning process since they fully engaged with it [15,28,30]. In addition, both teachers and students supported that the use of the ARGBL application can attract students' attention and increase their learning motivation [10,29,30,33] in the physics course. Finally, a well-structured experiment should be followed by the teachers, including a training session of how students can use the system, how they can interact with the QR code and what the process of the experiment is.

However, the proposed system has some limitations that merit further consideration in future work. Firstly, although our analysis is robust in small samples, a larger-scale experiment is necessary. In the midst of the COVID-19 pandemic, it was hard to have an adequate sample size, due to fact that the Greek schools, most of the school year, were closed. Secondly, the ARGBL application refers to a specific subject, namely, physics experiments in the fifth grade of a Greek primary school; therefore, the research results cannot be generalized to other learning topics and to other age groups. Therefore, our future plans are to extend the learning content of our proposed ARGBL application to other age groups by adding more exercises and experiments. Additionally, a long-term experiment would be necessary to further investigate the usability of the system and to extract valuable results about the learning outcomes of the students.

Author Contributions: M.Z. implemented the application and, together with C.V., E.K., T.S., conceived, designed and wrote this paper. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki and followed the regulations of the National Bioethics Committee. In our study the issue of personal data protection was confronted by keeping the anonymity of the participants, while informed con-sent was obtained.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: The authors of the paper wish to warmly thank the anonymous reviewers for their constructive comments, along with the teachers and director of the school for the hospitality and support offered.

Conflicts of Interest: The authors declare no conflict of interest.

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Processing Analysis of Swift Playgrounds in a Children's Computational Thinking Course to Learn Programming

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Abstract: Computational thinking courses can cultivate students' ability to apply logic in the fields of mathematics and information science. The new 12-year Basic Education Curriculum Guidelines were implemented in Fall 2019 in Taiwan. Courses on computational thinking, problem solving, and programming are contained in the technology education field in junior and senior high schools. Swift Playgrounds is an innovative app for the iPad and Mac that makes learning Swift interactive and fun. No programming knowledge is required to use Swift Playgrounds, making it very suitable for beginners. This study was carried out by letting elementary school teachers and students participate in Swift Playgrounds computational thinking courses. By trying this app, teachers of different disciplines attempted to realize more learning situations. Students learned how to cope with functions and loop skills by playing with "Byte", which is a character in Swift Playgrounds. There were three purposes for this study: first, designing a computational thinking course for the most basic part, "Hello! Byte", in Swift Playgrounds; second, assigning elementary school teachers to assess the qualitative analysis of tasks in Swift Playgrounds; and third, assigning elementary school students to do the tasks and assign a difficulty index in Swift Playgrounds after learning with this app. The results show that most teachers considered this approach to be able to improve logical thinking and inferential capability after assessing, and most students considered functions and loops quite difficult after using the app. According to the students' indices, about 86 percent of students considered that adding commands is easy, and about 37 percent of students considered that functions are easy. On the other hand, about 24 percent of students considered that applying the Slotted Stairways is difficult, and about 34 percent of students considered that using loops is hard. It is suggested that more instructions for the course or extendibility for classes is required.

Keywords: computational thinking; Swift Playgrounds; 12-year Basic Education; Bebras; programming

Citation: Cheng, G.-M.; Chen, C.-P. Processing Analysis of Swift Playgrounds in a Children's Computational Thinking Course to Learn Programming. *Computers* **2021**, *10*, 68. https://doi.org/10.3390/computers10050068

Academic Editors: Carlos Vaz de Carvalho and Antonio Coelho

Received: 30 March 2021
Accepted: 10 May 2021
Published: 20 May 2021

1. Introduction

Computational thinking through programming is attracting increased attention, as it is considered an ideal pathway for the development of 21st-century skills; this has led to K-12 initiatives around the world and a rapid increase in relevant research studies [1,2]. Computational thinking is considered an ideal skill for future development [3,4]. Educating future generations in programming and computational thinking is not trivial, and many different platforms and teaching approaches can be used for this purpose [5–7]. Swift is one tool for learning programming, and it is a development tool specially designed for designing iOS applications [8,9]. Swift Playgrounds, announced at the Apple Worldwide Developers Conference (WWDC) in June 2016, is an innovative and powerful app and an exceptionally simple way to build user interfaces across all Apple platforms using the power of Swift. It provides several-hour programming courses, suitable for children and beginners learning programming, and can build user interfaces for any Apple device using just one set of tools and APIs. Beginners can grasp the basic concept of using Swift through tasks, and the strong multitouch function allows easier learning of programming with Swift

Playgrounds. Simply by touching and dragging commands or inputting text and numbers, the users can interact with the game's role for programming and further learn the basic and solid grammar components of Swift, such as functions, loops, variables, parameters, and arrays [10].

Computational thinking is becoming more important in global information science and information curricula, and methods for including it in curricula are being sought [11–13]. More than 50 countries now participate in the Bebras challenge, which began in 2004. Its thematic short questions allow students from elementary schools through to senior high schools to solve problems online; the problem-solving time for each is about 3–5 min. Some computational thinking skills, e.g., mathematics, abstract making, computational thinking, problem solving, and estimation and induction, are also included. Bebras questions cover algorithms, data structures, programming, the Internet, databases, and social and moral issues [14].

In the experimental class in this study, 29 G5 students attended the 2018 Bebras International Challenge on Informatics and Computational Thinking in the first term and participated in the Swift Playgrounds computational thinking curriculum in the second term of the 2018 academic year. Practice with Bebras questions could train students' computational thinking capabilities, including programming capability, problem solving skills, decomposition of complicated tasks into simple components, algorithm design, and pattern recognition, to conform to the Curriculum Guidelines of 12-Year Basic Education—Technology, covering data representation, processing, analysis, algorithms, and information technology applications [15].

Consequently, this study aimed to (1) design a six-session Swift Playgrounds iPad app computational thinking course for elementary schools, (2) arrange for nine elementary school teachers to assess the tasks in the Swift Playgrounds iPad app and to provide qualitative analysis, and (3) arrange for 29 elementary school G5 students to provide difficulty analyses of task learning with the Swift Playgrounds iPad app.

2. Literature Review

Computational thinking [16,17] includes data collection, data analysis, pattern searching, abstract making, data resolution, modeling, and algorithms. Computational thinking can be applied in real life to break down problems, make complicated problems into simpler ones, and follow the context to solve problems and gain more information [18,19]. Its application to each subject is similar to including computational thinking in the technology field, in 12-year Basic Education [15]. A transnational study on robotics education between China and the USA developed a tool to evaluate elementary school G5 students' computational thinking capability, to assist students in learning problem challenges and computational thinking capability [20]. The Swedish government introduced digital computational thinking capability training courses and included them in the K-9 programming curriculum in 2018. More than 100,000 teachers had to learn programming and computational thinking instruction in a short period [21]. Such a changing trend of thought is unprecedented; even the 2019 12-year Basic Education Curriculum Guidelines in Taiwan stressed the teaching of a computational thinking curriculum.

For the challenge of computational thinking, the Italy Bebras official website [22] has provided services to teachers and students since 2015 to support task preparation and train students in solving problems; it manages about 25,000 teams and training courses. Lithuania and the UK have supported curriculum teaching and practice for the Bebras challenge, using the Bebras platform [14] to encourage students in information technology and computational thinking and educators in taking the computational thinking syllabus into account. The Bebras challenge provides creative and interesting tasks. Previous research [23] analyzed the Bebras task performance of 115,400 G3–G12 students in Italy, Australia, Finland, Lithuania, South Africa, Switzerland, and Canada; Bebras task performance data were collected and analyzed to reflect learning in computational thinking challenges. Algorithm and data representation questions dominated the performance of challenge tasks, comprising about 75–90%. For this reason, when providing teachers with a computational thinking curriculum, algorithm and data representation questions could be listed as the main points, and abstract, parallel, and question resolution items should be supplemental [24]. The author of [25] arranged for elementary school G5 students to participate in the 2017 Bebras International computational thinking challenge and discussed questions for elementary school students via Padlet and team discussion; the technology acceptance model tool was used for 333 students filling in feedback on the "perceived usefulness" of Padlet, and 74.4% of them considered it helpful.

In the Everyone Can Code plan in Chicago [26], the curriculum in the full-featured app was designed by Apple, allowing students to construct personal designs by exploring basic coding concepts. It provided all G3–G12 students with opportunities for coding education, as well as volunteers and students with opportunities for practicing programming in local enterprises to expand opportunities for students cultivating coding skills and inquiring into career development. KIBO's programming kit [27] was composed of 21 unique cards to assemble complicated sequences, including loops and conditional and embedded statements. Furthermore, in order to enhance interdisciplinary integration of STEAM, the tool contained various art creation materials for children making personalized products. Falloon indicated in research in 2016 [28] that the Scratch Jnr coding curriculum for students aged 5 and 6 in New Zealand provided an important method to train students in complicated computational thinking and critical thinking ability, and it provided critical evidence for teachers of the students' thinking processes in computational tasks. Regarding the coding curriculum in elementary schools in Italy [29], vocational high school students, in the theoretical framework provided in computational thinking, taught junior high school and elementary school students to use the App Inventor to create apps on smartphones in an Android environment; this formed an interesting cooperation pattern between elementary schools and high schools.

3. Research Method and Results

A survey research method was utilized in this study. The researcher instructed a G5 computer class. The designed teaching process contained 6 sessions, with 1 session (40 min) per week practiced in the computer class. Nine teachers from different fields were invited to try out and assess the "Hello! Byte" computational thinking curriculum on Swift Playgrounds, and 29 students learnt the "Hello! Byte" computational thinking course on Swift Playgrounds. After participating in the experiential learning, teachers and students responded to a Google form to explain their qualitative analysis and difficulty analysis of the computational thinking curriculum. In Figure 1, the Google Form of the feedback for the degree of difficulty is shown in the screenshot. In Figure 2, the screenshot on the left is the role of "Byte" in the Swift Playground app, and the one on the right presents the scene of the task for the coding game.

3.1. Teaching Process Design and Feedback Analysis after Students' Learning of Swift Playgrounds Computational Thinking

A Google form was used to collect difficulty feedback from the 29 elementary school G5 students after they learned the Swift Playgrounds computational thinking curriculum, from Task I to Task VIII, for six sessions (240 min). The feedback was analyzed using a Google form linear scale (the most difficult tasks were given a score of 1, the easiest tasks were given 10). The researcher proposed a linear difficulty scale of 1–3 as difficult, 4–7 as moderate, and 8–10 as easy, as shown in Figures 3–12.

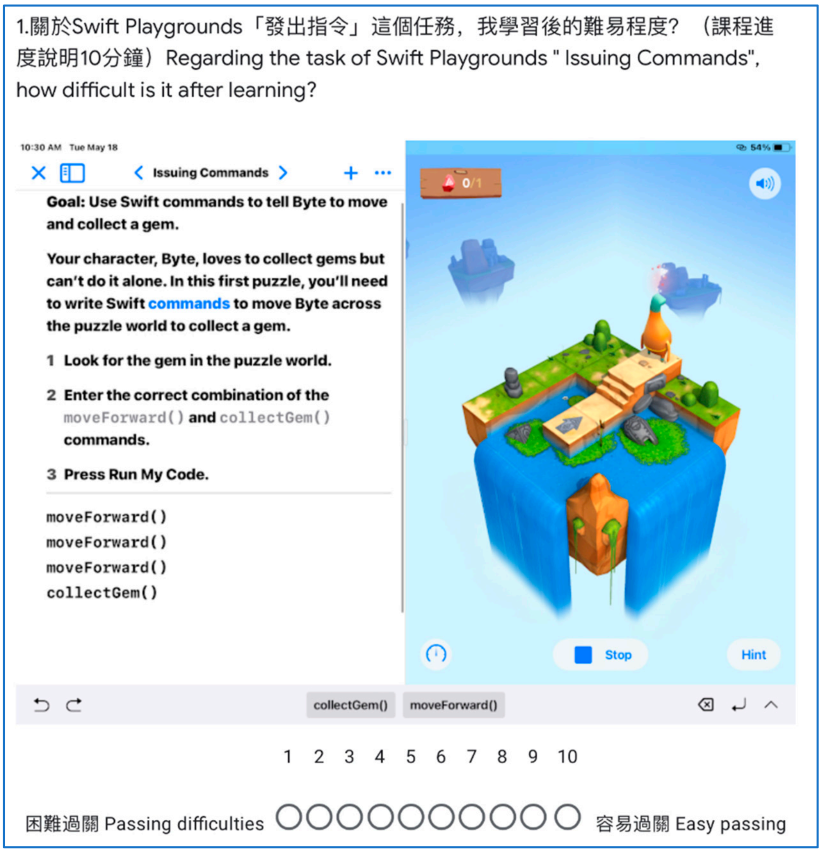

Figure 1. The Google Form of the feedback for the degree of difficulty was shown in the screenshot. The Chinese meaning of this picture is the feedback of the degree of difficulty for Task I "Issuing Commands".

Figure 2. The Screenshot of the Swift Playground app presents the role of "Byte" and the scene of the task for the coding game (Retrieved 13 October 2020, from https://www.apple.com/swift/playgrounds, accessed on 13 October 2020).

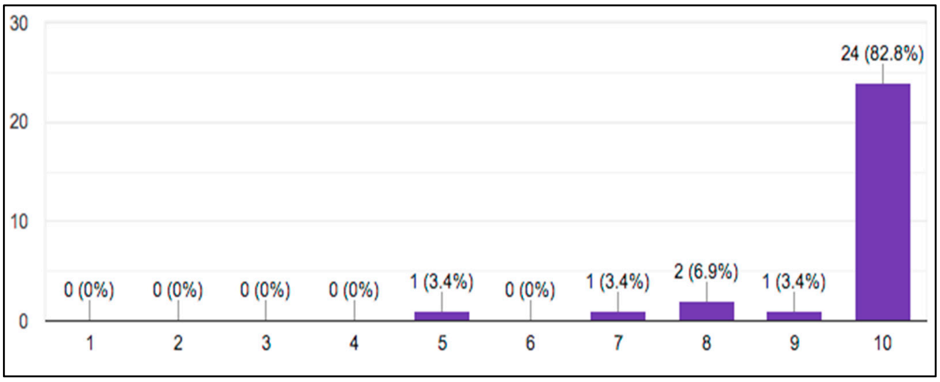

Figure 3. Difficulty analysis of Task I: "Issuing Commands".

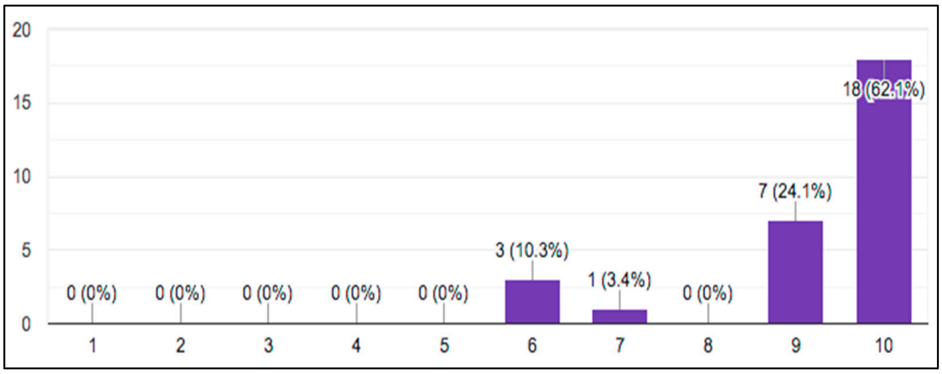

Figure 4. Difficulty analysis of Task II: "Adding a New Command".

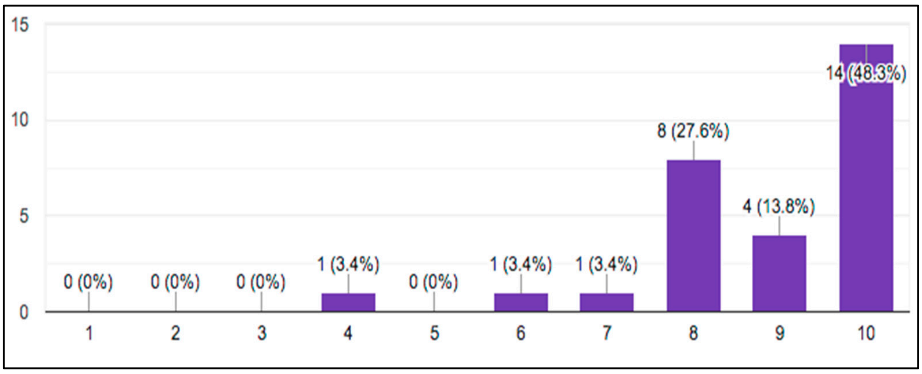

Figure 5. Difficulty analysis of Task III: "Toggling a Switch".

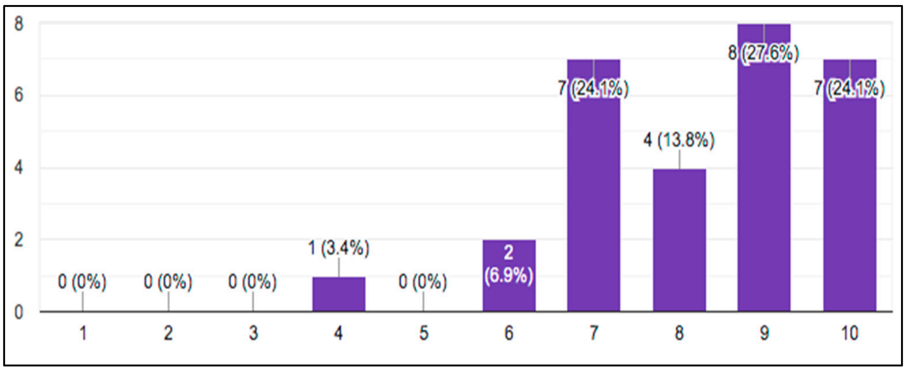

Figure 6. Difficulty analysis of Task IV: "Portal Practice".

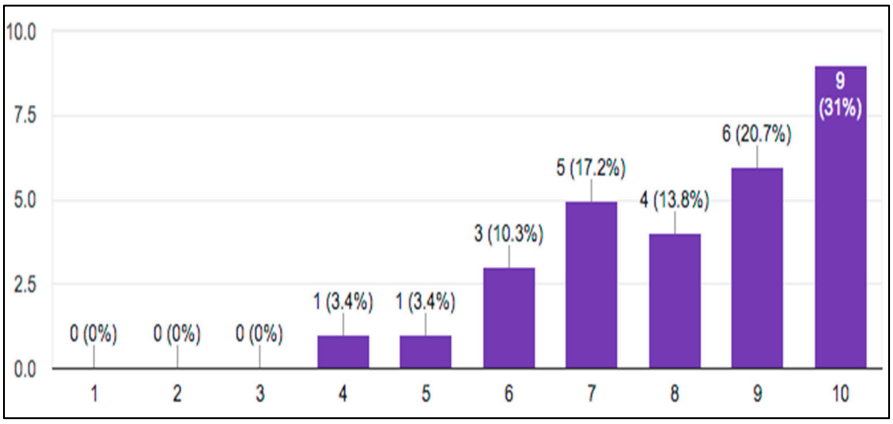

Figure 7. Difficulty analysis of Task V: "Composing a New Behavior".

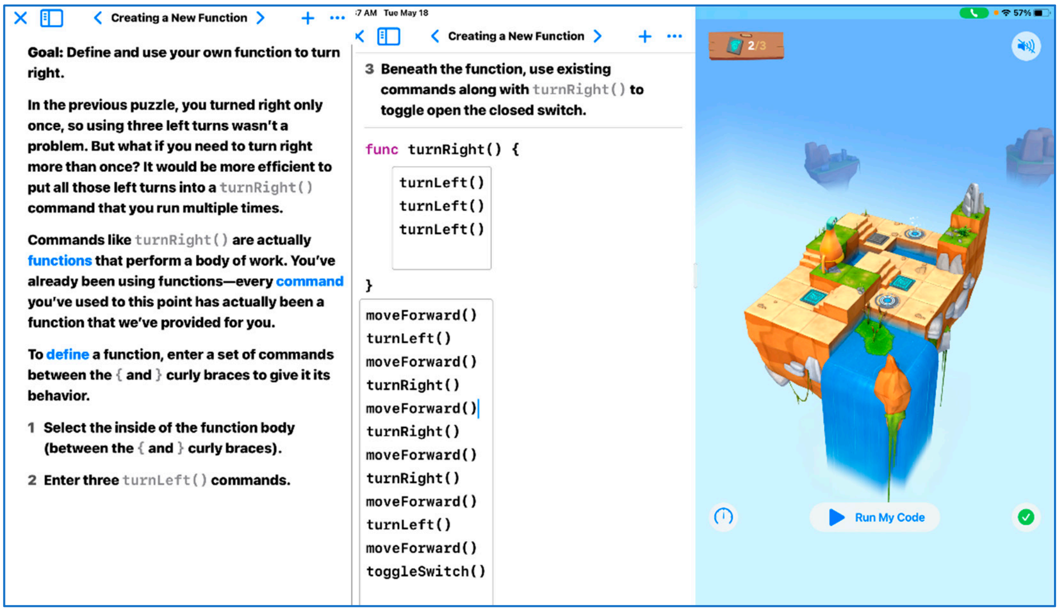

Figure 8. Task VI: "Creating a New Funtion".

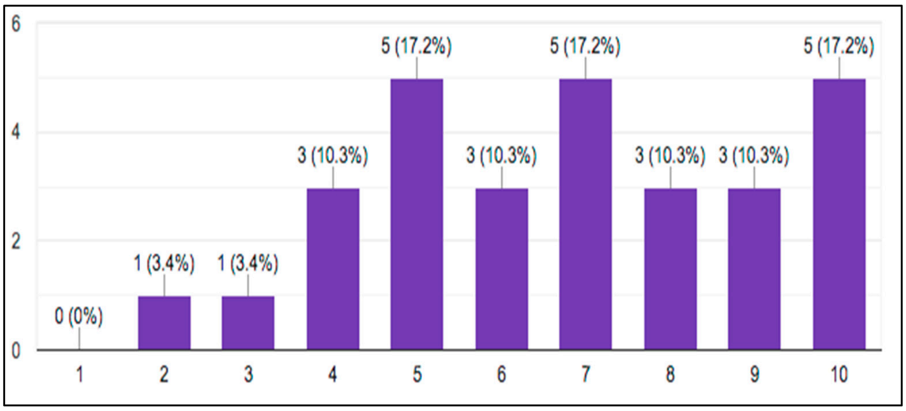

Figure 9. Difficulty analysis of Task VI: "Creating a New Funtion".

Figure 10. Task VII: "Slotted Stairways".

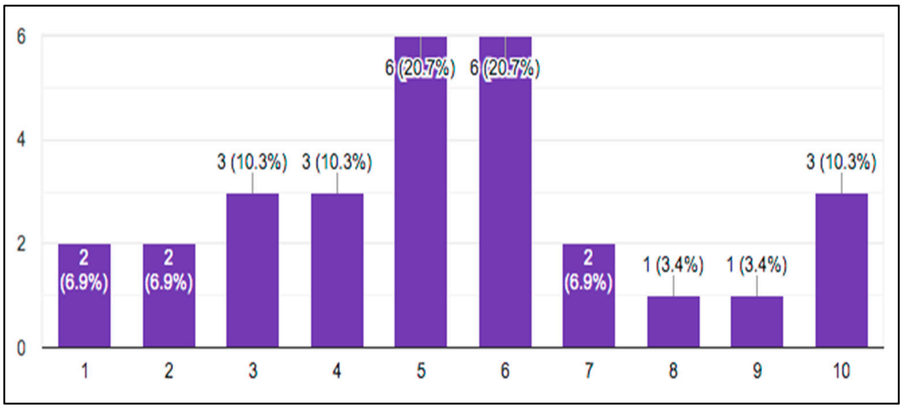

Figure 11. Difficulty analysis of Task VII: "Slotted Stairways".

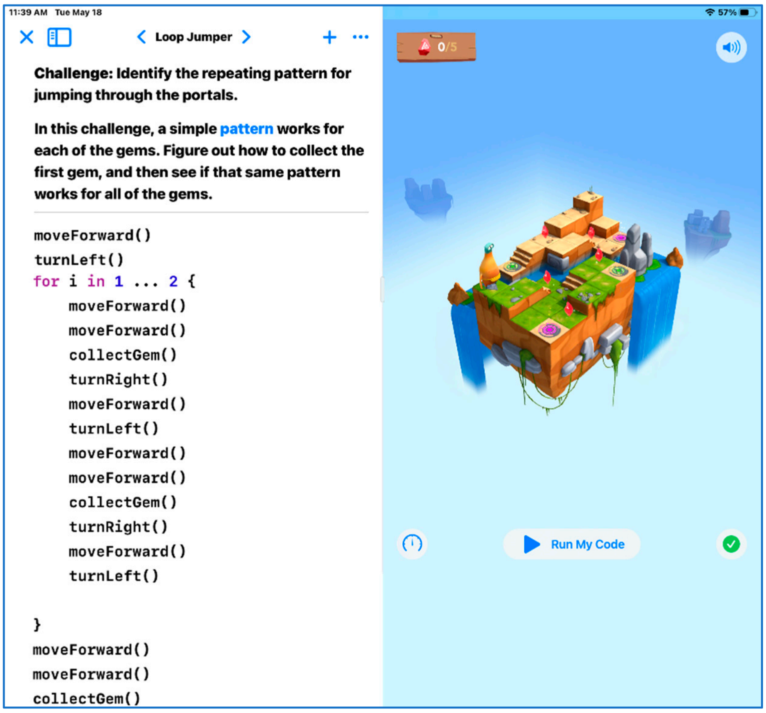

Figure 12. Task VIII: "Loop Jumper".

3.1.1. Coding Command (80 min)

Task I: Preceding the "Issuing Commands" task in "Hello! Byte" on Swift Playgrounds, the teacher displays the iPad picture, prompts task goals, touches it with their finger, and writes to add commands moveForward() and collectGem(). After adding the commands and pressing "execute my code" on the picture, the "Byte" moves forward 3 steps (1 step for going up/down the stairs), collects jewels, and reaches the destination. In Figure 3, the result of the difficulty analysis for class students learning Task I: "Issuing Commands", 24 students, among the 29, considered the degree of ease to be 10 (82.8%), 1 student considered the degree of ease to be 9 (3.4%), and 2 students considered the degree of ease to be 8 (6.9%). In total, 27 students (93.1%) considered Task I: "Issuing Commands" to be easy.

Task II: Preceding the "Adding a New Command" task in "Hello! Byte" on Swift Playgrounds, the teacher demonstrates the iPad picture, prompts task goals, continues the previous task, and adds the command turnLeft(). After adding the command and pressing "execute my code" on the picture, the "Byte" moves forward 2 steps, turns left, moves forward 2 steps, and collects jewels to reach the destination. In Figure 4, the result of the difficulty analysis for class students learning Task II: "Adding a New Command", 18 students considered the degree of ease to be 10 (62.1%) and 7 students considered the degree of ease to be 9 (24.1%). In total, 25 students (86.2%) considered Task II: "Adding a New Command" to be easy.

Task III: Preceding the "Toggling a Switch" task in "Hello! Byte" on Swift Playgrounds, the teacher displays the iPad picture, prompts task goals, continues the previous task, and adds the command toggleSwitch(). After adding the command and pressing "execute my code" on the picture, the "Byte" moves forward 2 steps, turns left, moves forward, collects jewels, moves forward, turns left, moves forward, and performs a Toggling a Switch to reach the destination. In Figure 5, the result of the difficulty analysis for class students learning Task III: "Toggling a Switch", 14 students considered the degree of ease to be 10 (48.3%), 4 students considered the degree of ease to be 9 (13.8%), and 8 students considered the degree of ease to be 8 (27.6%). In total, 26 students (89.7%) considered Task III: "Toggling a Switch" to be easy.

Task IV: Preceding the "Portal Practice" task in "Hello! Byte" on Swift Playgrounds, the teacher demonstrates the iPad picture, prompts task goals, continues the previous task, and adds the command toggleSwitch(). After adding the command and pressing "execute my code" on the picture, the "Byte" moves forward 3 steps, turns left, moves forward 2 steps, does a Toggling a Switch, moves forward, enters the Portal, exits the Portal, moves forward, turns left, moves forward 2 steps, and collects jewels to reach the destination. In Figure 6, the result of the difficulty analysis for class students learning Task IV: "Portal Practice", 7 students considered the degree of ease to be 10 (24.1%), 8 students considered the degree of ease to be 9 (27.6%), and 4 students considered the degree of ease to be 4 (13.8%). In total, 19 students (65.5%) considered Task IV: "Portal Practice" to be easy.

3.1.2. Building Functions (80 min)

Task V: Preceding the "Composing a New Behavior" task in "Hello! Byte" on Swift Playgrounds, the teacher displays the iPad picture, prompts task goals, adds the following commands, and presses "execute my code" on the picture. The "Byte" moves forward 3 steps, turns left 3 times (without the command to turn right), moves forward 3 steps, and collects jewels to reach the destination. In Figure 7, the result of the difficulty analysis for class students learning Task V: "Composing a New Behavior", 9 students considered the degree of ease to be 10 (31%), 6 students considered the degree of ease to be 9 (20.7%), and 4 students considered the degree of ease to be 4 (13.8%). In total, 19 students (65.5%) considered Task V: "Composing a New Behavior" to be easy.

Task VI: Preceding the "Creating a New Funtion" task in "Hello! Byte" on Swift Playgrounds, the teacher demonstrates the iPad picture, prompts task goals, and establishes a turnRight() function by adding the command turnLeft() 3 times in func turnRight(){ }, and subsequently uses the function to complete the program command and function, as shown in Figure 8. By pressing "execute my code" on the picture, the "Byte" moves forward, turns left, moves forward, turns right, moves forward, turns right, moves forward, enters the Portal, exits the Portal, turns right, moves forward, turns left, moves forward, and does a Toggling a Switch to reach the destination. In Figure 9, the result of the difficulty analysis for class students learning Task VI: "Creating a New Funtion", 11 students (37.8%) considered Task VI to be easy (degree of ease 8–10), 16 students (55%) considered Task VI to be moderate (degree of ease 4–7), and 2 students (6.8%) considered Task VI to be difficult (degree of ease 1–3).

Task VII: Preceding the "Slotted Stairways" task in "Hello! Byte" on Swift Playgrounds, the teacher displays the iPad picture and prompts the task picture and goals as in the following figure. The "Byte" repeatedly collects jewels back and forth. This major task can be decomposed into 3 minor tasks, which are simplified with functions or commands for subsequent use of the Slotted Stairways. To practice the establishment of the collectGemTurnAround() function, in Figure 10, the commands to move forward 2 steps, collect jewels, turn left twice (turn backward), and move forward 2 steps are added in func collectGemTurnAround(){ }. To practice the establishment of the sloveRow(){} to complete the minor task of collecting 2 jewels, on the left of the figure, the commands collectGemTurnAround() 2 times, turn left 3 times (turning right), move forward, and turn left are added in func sloveRow(){ }. By pressing "execute my code" on the picture, the "Byte" executes the different commands, functions, and Slotted Stairways. In Figure 11, the result of the difficulty analysis for class students learning Task VII: "Slotted Stairways", 5 students (17.1%) considered Task VII to be easy (degree of ease 8–10), 17 students (58.6%) considered Task VII to be moderate (degree of ease 4–7), and 7 students (24.1%) considered Task VII to be difficult (degree of ease 1–3).

3.1.3. Building Loops (80 min)

Task VIII: Preceding the "Loop Jumper" task in "Hello! Byte" on Swift Playgrounds, the teacher demonstrates the iPad picture and prompts task pictures and goals. To find the step for repeatedly operating tasks on the picture, the part which is to be repeatedly executed can be searched on the task picture. After adding commands to move forward 2 steps, collect jewels, turn right, move forward, turn left, move forward 2 steps, collect jewels, turn right, move forward, enter Portal, exit Portal, and turn left for *i* in 1 . . . 2 { }, "execute my code" in the picture is pressed to have the "Byte" move forward, turn left, repeat the above loop twice, move forward 2 steps, and collect jewels to reach the destination, in Figure 12. In Figure 13, the result of the difficulty analysis for class students learning Task VIII: "Loop Jumper", 5 students (17.1%) considered Task VIII to be easy (degree of ease 8–10), 14 students (48.2%) considered Task VIII to be moderate (degree of ease 4–7), and 10 students (34.4%) considered Task VIII to be difficult (degree of ease 1–3).

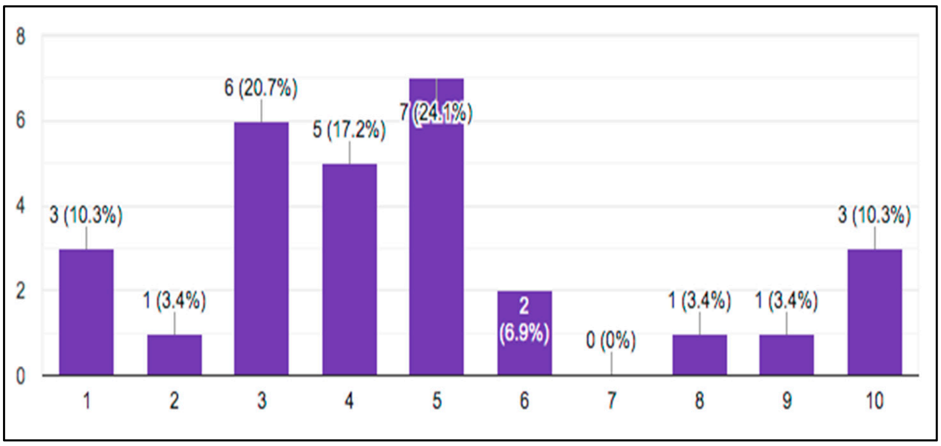

Figure 13. Difficulty analysis of Task VIII: "Loop Jumper".

The students are requested to fill in the Google form "student feedback on iPad Swift Playgrounds learning".

3.2. Qualitative Feedback Analysis after Teachers' Assessments of Swift Playgrounds

Nine teachers—2 gifted education program teachers, 2 English teachers, 2 ICT teachers, 2 science teachers, and 1 art teacher—were asked to assess the Swift Playgrounds iPad app. During the Professional Learning Community (PLC) gathering time, lasting about 2 h, they learned computational thinking and programming on their own and then filled in the Google form. From Table 1, which presents qualitative feedback analysis of the teachers' assessments of the computational thinking curriculum, most teachers considered that the basic course "Hello! Byte" on the Swift Playgrounds iPad app could train logical thinking and reasoning ability to largely help beginners learn a basic programming.

Table 1. Qualitative feedback analysis after teachers' assessments of Swift Playgrounds.

Teacher	Subject	The Most Impressive?	Importance of Programming to the Future?
Teacher A	gifted education program	The picture is exquisite and cute and the instruction steps are clear for self-learning.	Helps students dismantle problems, think of problem-solving steps, and write the steps with a specific execution sequence.
Teacher B	gifted education program	A fun program. Hopefully, I can continue to play and learn at home.	Everything could be controlled with programs. It allows me to realize that there are still many things to invent.
Teacher C	English	It is interesting to combine English with coding, and would be motivating for learning English.	Trains logic thinking, reasoning, computation, and, of course, English ability.
Teacher D	information technology education	It teaches programming with a drag-and-drop app and is presented with text, allowing students to get into the programming world earlier. It is impressive.	The app could train personal logic and allow oneself to better organize both programs and life. It is an excellent app.
Teacher E	science and technology	It combines complete space and logic concepts to easily attract learners practicing the course step by step. It is a good teaching material.	Nil
Teacher F	English	After comprehending the hierarchical learning process, it is easy to execute.	It allows for learning different languages and cultivating logic reasoning capability.
Teacher G	art and humanities	It is quite interesting and needs time for solving problems.	It could be combined with information technology to enhance students' learning interests.
Teacher H	information technology education	It has a rich picture/text interface to largely help beginners learn basic programming design.	Basic logic concept establishment and simple programming applications.
Teacher I	science and technology	It could train logical thinking and reasoning capability. Tasks are interesting.	Structured learning.

4. Conclusions and Suggestions

In the 12-year Basic Education practiced in 2019, the technology field reinforced problem solving and programming in computational thinking. This study re-wrote a lesson plan for technology pilot schools in the 2018 academic year into a paper. Computational thinking skills are becoming essential in all aspects of work and life and have become a part of the K-12 curriculum around the world [30]. For the many different program languages and computational thinking courses, the use of different training and learning tools has essential learning effectiveness [20,31–33]. In the study, a Swift Playgrounds computational thinking curriculum, lasting six sessions, was first developed, and nine elementary school teachers were asked to assess Swift Playgrounds. It was discovered that the tool could train students in logical thinking and reasoning capability. After the research, most teachers considered the tool as being able to train logical thinking and reasoning capability. Analysis of the students' learning feedback showed that 86% and 37% of students regarded adding commands and functions, respectively, as being easy, while 24% and 34% of students considered applying the unit step function and using loops, respectively, as being difficult. It is suggested that the curriculum should be explained in detail, or the schedule extended to allow most students to keep up with the schedule.

Before the end of the course, the teacher announced the codes for all tasks. This allowed students to build the learning scaffold and complete task operations more fluently during self-learning. All students were asked to fill in their feedback on a Google form in the last session, for summative evaluation. Swift Playgrounds is an iOS app. It can only be learned on an iPad, and most schools in the nation could not furnish each student, or even each class, with an iPad for this learning experience. A class was therefore arranged for trial teaching in this study. For a second class, we would need to establish students in different classes but with the same seat number on Swift Playgrounds for the "Hello! Byte" course. These restrictions might be factors that adversely affect the popularity of the course. Apple could release the app for different platforms to allow access to more teachers and students for learning.

Author Contributions: Data curation, G.-M.C.; validation, C.-P.C.; writing—original draft, G.-M.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Institutional Review Board.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Conflicts of Interest: The authors declare no conflict of interest.

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Article

Supporting School Aged Children to Train Their Vision by Using Serious Games

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Citation: Heldal, I.; Helgesen, C.; Ali, Q.; Patel, D.; Geitung, A.B.; Pettersen, H. Supporting School Aged Children to Train Their Vision by Using Serious Games. *Computers* **2021**, *10*, 53. https://doi.org/10.3390/computers10040053

Academic Editors: Carlos Vaz de Carvalho and Antonio Coelho

Received: 1 March 2021
Accepted: 7 April 2021
Published: 16 April 2021

Abstract: Several children struggle with vision difficulties caused by problematic coordination between their left and right eye muscles, i.e., oculomotor dysfunction (OMD). Many OMDs can be improved by training the eyes via physical exercises defined and supervised by vision experts. The aim of this paper is to investigate the feasibility of utilizing Serious Games (SGs) and eye-tracking technologies (ETs) for training the eyes of children having OMD. Via these activities, a trainee can, with her eye gaze, follow objects which are moving, change their directions and speed, or pop up on the screen. The results present mapping the current physical training goals to activities for SGs using input from ETs, and illustrate this correspondence for designing and developing six games. The games' feasibility evaluation is done via semistructured interviews and evaluating user experiences. Three vision teachers (VTs) were involved in design and development, ensuring achievement of training goals, and five VT students in evaluations. The findings demonstrate the potential of using SGs and ETs to train OMD and point to future needs for improvements.

Keywords: OMD; eye-tracking; serious games; training; vision impairment; rehabilitation; vision teachers

1. Introduction

Vision plays a leading role in our daily activities, influencing our interaction with the outside world. Of all school-aged children, 25–30% have vision problems [1], and many of these were not detected before [2,3]. A child who can clearly see objects at a certain distance can still have a functional vision impairment at other distances [4].

Vision impairments can cause later impediments in academic success, and by this is influencing the education system, public health system, and social well-being [5–7]. A particular part of vision impairments can be corrected by glasses or surgery. A large number of school-aged children (17–30%), such as those having Oculomotor Dysfunctions (OMD), can be helped via vision therapy or training their eyes.Already a few weeks of training can improve their vision [4,8–10]. By school-age children, we mean children who are beginning their school education. OMD hinders automatic control of one's eye muscles for more extended periods than a few seconds, which results in reading or seeing difficulties. Adults also can have OMD, especially after a brain injury [11]. However, they can articulate their problems, while many children are unaware of having OMD and cannot understand its negative influence on their performance [4]. OMD is difficult to detect due to missing resources to screen all school-aged children [4,12]. Since rehabilitation or training takes longer time periods it is even more challenging to support it [13].

In many countries, the last mandatory control of eyes is with a health control at the age of 3–4, while in contrast, their sight is still under development when they begin school [5,14].

A hypothesis behind this work is that supporting technologies would reduce resources for experts or parents responsible for improving children's vision problems. The first step towards this is investigating how technologies can complement the current physical training of OMD.

While the "end-users" of rehabilitation are children having OMD, the enablers for training and using these technologies as new and complementing methodologies for traditional training are the professionals suggesting and often supervising training. This work focuses on these professionals, the special educators, which are also called vision teachers (VTs). VTs are responsible for children's vision impairments and understanding teaching and education activities [13].

The aim of this paper is to illustrate how serious games (SG) and eye-tracking technologies (ETs) can complement vision training for children with OMD from the perspective of vision teachers (VTs). This is done by describing current training, identifying possible SG support, and testing the feasibility of SGs by VT students. There have been three VTs involved in developing games and five VT students in evaluations. The methodology is inspired by Grounded Design methodology [15], ending with a feasibility study of six SG prototypes based on data from semistructured interviews and user experience evaluation [16,17].

One of the main challenges of this work has been to work interdisciplinary and translate the physical guidelines the VTs identified to improve OMD in children via vision training to guidelines needed for developing games. Another challenge has been to systematically compare the visual stimuli on the computer screen with the physical eye exercises. This paper defines and evalautes the suggested prototypes and describes challenges for further development.

The limitation of this study is in evaluations with end-users. To carry out experiments in children and test the progress and outcomes of using this type of training needs to be done in the next step. However, this step cannot be conducted before investigating the usefulness of the games with vision experts. This paper focuses on VTs as a main stakeholder group, enabling vision training in children.

The structure of this paper is the following. After presenting the literature background (Section 2), we describe the study design via applied methods and materials (Section 3). This is followed by the results (Section 4) in three subsections—the first presents the activities needed to be done during physical vision training. The next examines how these activities can be mapped and triggered with playing SGs. The last subsection contains feasibility evaluation of the suggested SG prototypes by the VTs. The last Sections are the Discussion and future work (Section 5) and Conclusions (Section 6).

2. Literature Background

2.1. OMD as a Vision Impairment That Can Be Supported with Vision Training

Good vision is vital for cognitive, physical, and social progress during early childhood and into later years. Many vision problems can be corrected by eyeglasses [18], contact lenses, or laser refractive techniques [18,19], and many, often the functional eye motoric problems, can be improved by training [4].

Some possible reasons for functional vision problems such as OMD in children are innate, brain abnormalities, unmatured muscles, stress, or too little stimulation. [20].

A significant number of children (17–30%) with OMD have normal vision acuity (sharp vision), but insufficient eye motoric abilities [4]. OMD is associated with problems in coordinating the movements of the eyes (mainly measured via fixation, saccade, and smooth pursuit). A fixation is an ability to pause the eye movement on a particular region for gathering visual information [21]. A saccade is a rapid change of fixation to another fixation [22]. Smooth pursuit occurs when an eye tracks a moving object [23]. A person having anomalies in any of these three eye movements can be diagnosed with OMD. OMD may lead to difficulty to read, difficulty to write, eye fatigue, headache, poor development in eye-hand coordination, or eye fixation loss [9,24]. Children with learning disabilities often have vision problems related to OMD [21,22], and many of them can be helped by timely access to quality eye care [25].

There are several vision experts who provide screening (identification) or treatments (rehabilitation) of eye problems [26]. These are vision specialists, such as ophthalmologists, optometrists, orthoptists and dispensing opticians, often focusing on different parts of the eyes. Many of them, e.g., ophthalmologists, don't necessarily understand how important the children's visual function is, e.g., vision balance or eye accommodation [27]. If an ophthalmologist sees "vision screening," they mainly think about eye diseases, identifying problems that can be corrected via prescriptions of medicine, eyeglasses, or contact lenses. The focus in this paper is vision screening focusing on identifying functional eye problems and vision training for improving these. In Norway and in many other countries the special educators with competence in vision, the vision teachers (VTs), are the main responsible for identifying such problems.

For OMD problems, VTs guide rehabilitation, which includes usually more than three weeks. To support these activities may involve other, often nonprofessional stakeholders, e.g., school teachers or parents. While the effect of vision training in general has been highly debated for several decades [28], there is evidence for the positive effects of vision training [29]. Research and practical studies tested the impact of training the eye-muscles in children with OMD, and found significant improvements in reading skills and decreased duration of unnecessary gaze fixations already after three weeks of regular training [30–33]. The length of the training varies, depending on who defined it the type of the OMD problem and the child. As there is no consensus about an exact test battery for vision screening identifying OMD, there is no consensus for a vision training method. Usually, several exercises are recurring in the different batteries.

Vision training batteries are developed by VTs and include exercises where the children need to move their eyes or focus on particular objects in the surrounding environment. These exercises can be as simple as following a pen back and forth, from left to right or up and down, or more complex, e.g., throwing a ball back and forth, working with puzzles, drawing through a maze using a pencil, jumping around on one leg or finding matching items in a pile [34]. Some of the exercises involve books, and others involve working with paper figures (see Figure 1). Some of the exercises require the participant to sit still, while others encourage full-body movement. Especially at the start many of the activities need help from an expert, being either a VT, or a vision therapist, but later may be complemented or replaced by the assistance from educated teachers or parents in the children's network. There is often a need for creating an individual training program and a personalized set of exercises depending on the diagnosed problem. Depending on the progress the training may also be changed by the experts.

Expertise and planning is needed to design these exercises and make them attractive to children. Therefore, to define adequate training, creativity is an essential aspect VTs need to posses, besides having deep insight into vision problems. Motivating young children to perform repeated activities several times is not easy. Additionally, a VT needs to develop ideas for exercises to fit the individual's specific needs.Ensuring that movements are correctly performed, the VTs can use anaglyphs, lenses, septa, stereoscopes, computer programs, paper, pencil, and miscellaneous tasks in the office and home vision training sessions [35].

Many of the VTs do not have experience in using ET technologies today. Those who are familiar with computerized solutions are using e.g., using *Visagraph* (https://www.readingplus.com/visagraph/ (accessed on 14 April 2021)) and *ReadAlyzer* (Information of the recently improved ReadAlyzer 2K can be seen at https://www.compevo.se/ (accessed on 14 April 2021)) reading assessment kits for the vision assessment [36]. While considerable attention is on developing technologies supporting reading in general (see Figure 2a,b), the focus of this study is not on reading proficiency, but on connecting eye problems to several problems, such as reading.

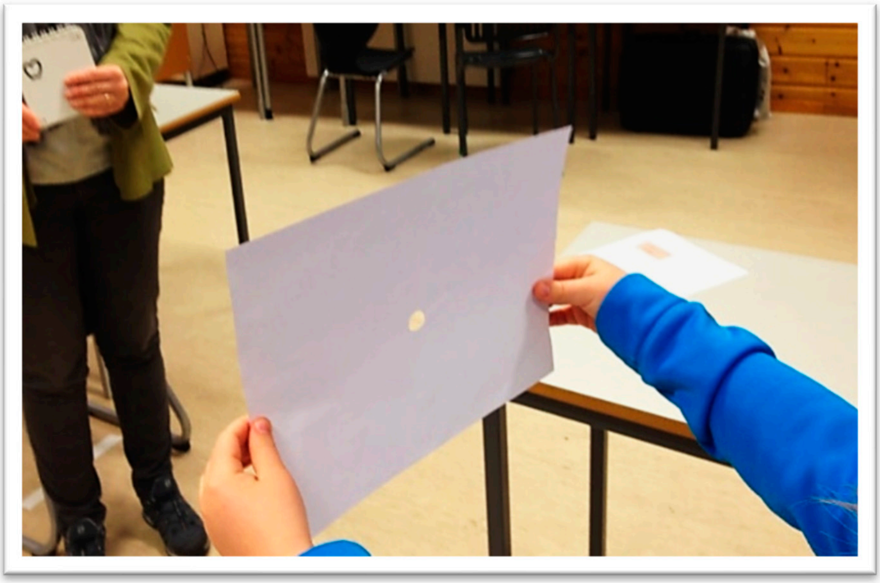


Figure 1. An exercise requiring papers (the child holds it) and pictures (in the hand of a VT) to examine distance eye dominance.

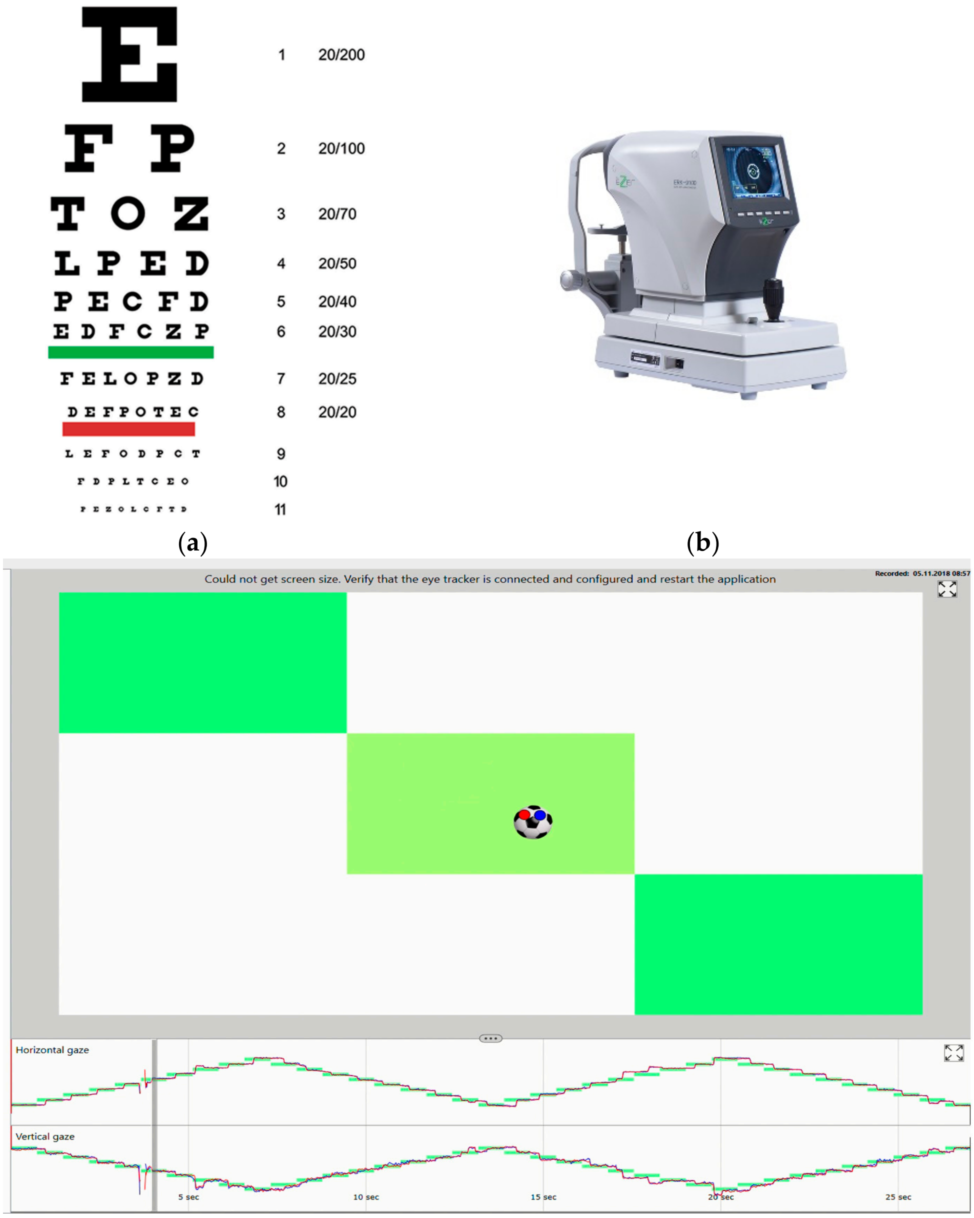
2.2. The Role of Eye-Trackers in Vision Screening and Training

One method for studying eye movements is to track the point a user is looking at with ET technology (see Figure 2c). ETs are mainly used to determine the focus of visual attention on the screen or in the environment. An ET records the gaze position while the eyes are looking at a stimulus in real-time [35]. There are numerous ET applications used in research, many in marketing or evaluating the usability of interfaces [37–39].

ET technology has been a successful research tool used in the clinical settings for the diagnosis of patients in psychology, neurology, and ophthalmology [40]. It is widely used in clinical applications for diagnostic and screening purposes or to detect various disorders and home-based rehabilitative treatments [41]. Graphical representations on a screen can both be attention catching and can be followed by subjects who cannot read. Therefore, combining the use of ETs and graphical images with for instance SGs can be considered helpful methods to examine eye problems in youngsters [36,42].

In order to support screening OMD vision impairments, ETs need to be able to register the movements from the left and right eyes separately and correctly and examine these together with information from the environment. The environment is needed for references, e.g., knowing what one is looking at and for how long time, is important to determine visual attention. Figure 2 illustrates some conventional, instrumental, and software-based vision screening tools.

There are efforts to make ETs small and affordable devices for this; at the present stage, there are no commercially available small devices, e.g., mobile phones or tablets, which can be calibrated well [45] or which can measure the left and the right eye movements separately. Similarly, algorithms for handling ET with good enough accuracy for measuring eye movements in immersive environments, e.g., for using HMDs, are complex [46]. Additionally, HMDs with good enough ETs are quite expensive. Therefore, rehabilitation exercises utilizing the entire space need to be improved for better supporting vision training. Todays' vision training is based on exercises using the surrounding space, with possibilities to be complemented by computer-supported exercises. The exercises are seldom connected directly to measuring eye movements. One of the overall goals of this study is to design and develop such exercises, i.e., to automatically follow and measure a child's eye movements when she is training her eyes.



(**a**) (**b**)

(**c**)

Figure 2. Different tools and software programs supporting vision screening: (**a**) Snellen chart [43] used for traditional vision screening; (**b**) Ezer (http://usophthalmic.com/Ezer-ERK-9100-Autorefractor-Keratometer (accessed on 14 April 2021)) autorefractor is an instrumental device used for measuring refractive error; (**c**) C&Look [44] is an ET based computer software for screening OMD.

ETs can detect and record eye movements following the point of gaze continuously. Figure 3 illustrates a picture from a video recording of a child following a frog via an ET and her left (blue) and right (red) eye gaze on the screen. Having the video recording and the eye positions from an ET, one can measure and visualize coordination problems between the left and right eyes. The background is divided into nine zones. The green color indicates that the child who screens her eyes has a good vision in the respective zones on the screen. The colors of the zones can vary from darker green, lighter green, darker yellow, lighter yellow, lighter red, and red. Depending on the un-correlation between the eye movements, the colors indicate the severity of the observed eye problems.

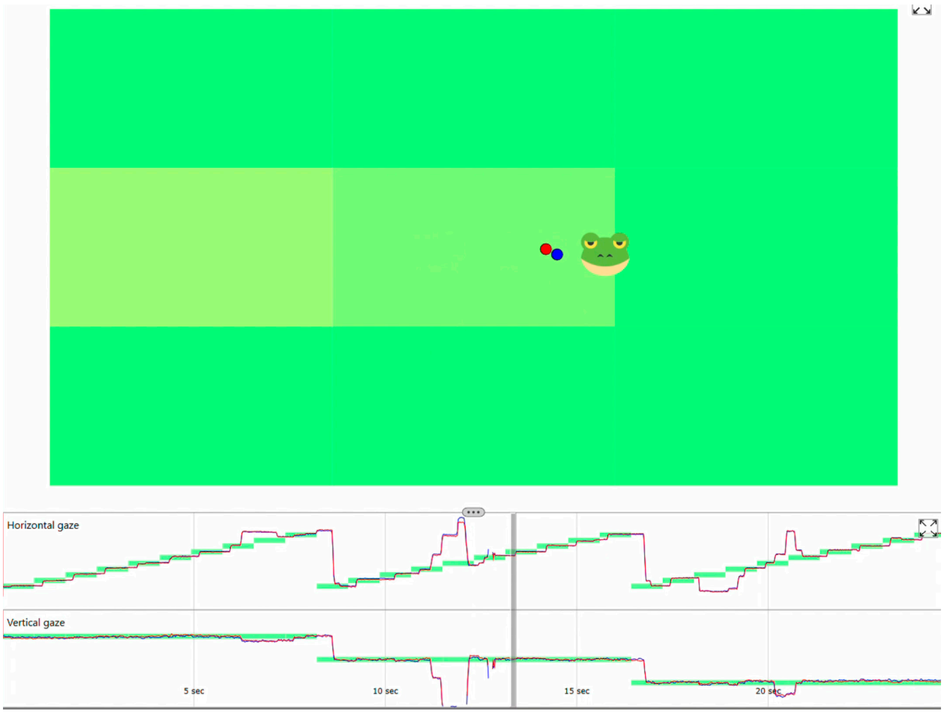


Figure 3. The video follows the frog's graphical representation on the screen superimposed by the representation of the eye gaze from the left and right eyes. The movement of the frog was from up to down (and from left to right). The two lines in the bottom show (problems with) smooth pursuit movements after 11–12 s.

Creating an associated program that can be used after the test to see the eye movements by visualizing these during the performance gives an opportunity to detect eye misalignment. Such programs are e.g., RightEyes program [47] or C&Look [48]. Figure 4 illustrates how the left and right eyes diverge for a child with OMD for saccadic problems in a left eye, during a given time. The left eye movement is visualized with the blue line and the right with the red line. The horizontal eye movements are visualized by the lines on the upper part and vertical movements on the lower part of Figure 4.

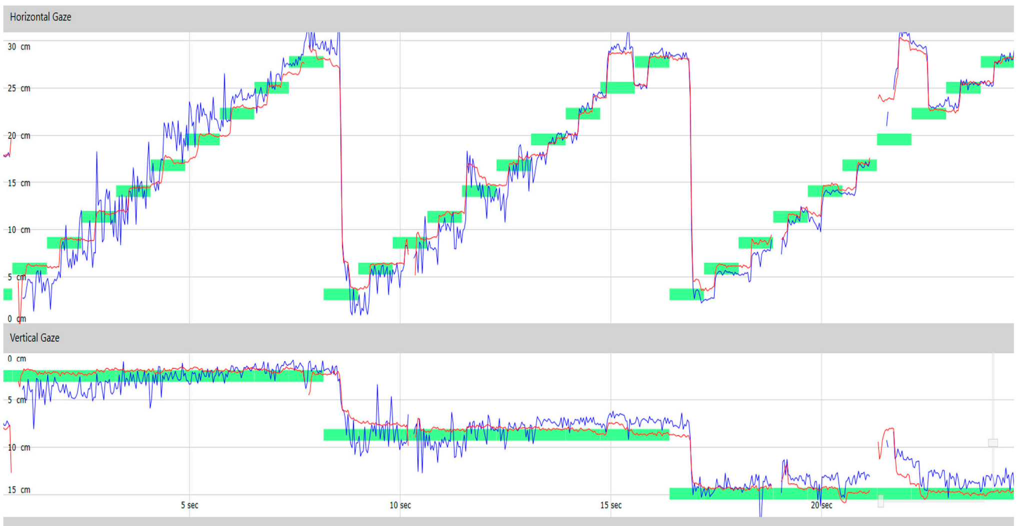


Figure 4. ET-based OMD examination program (via C&Look [48]) showing saccadic movements with left eye (vibrating) problems. The green line illustrates the "normal" area.

This work builds on the C&Look software for identifying (but not training) OMD problems [44,49]. The C&Look software uses visual tasks to stimulate the eyes of the participants and records their eye trace via an ET. The tracker records multiple metrics such as the Point of Gaze (POG), meaning the point on the screen where the participants' eyes are directed, fixations, saccades, and smooth pursuit. This data is then visualized by using plots so that the discrepancy between the left and right eyes can be examined and quantified, as is shown for saccadic vision problems in Figure 4.

The idea for this C&Look is based on the idea from an earlier, MS-DOS-based non-portable technology developed in the 1980s in Sweden. This MS-DOS-based technology is still in use by the center for special education in Oslo, Norway. C&Look was found equally good to recognize OMD problems as solutions using more expensive ETs by several classes of children [50] and the cheaper version is used in follow up studies in Norway and Tanzania.

2.3. Serious Games and Other Technologies Supporting Vision Problems

Several training software based on Serious Games (SG) offer improvements with increased motivation and high user experiences, especially for younger children [51]. Digitizing and gamifying the training and learning has several advantages: it makes it more motivating to perform exercises [52,53] which focus on learning basic, often boring things, e.g., methods in engineering [54], or allowing repeated training for increasing skills and competencies in handling emergency cases [55–57].

SG is used on several platforms and often incorporates new technologies. Examples are: using mobile technologies to allow learning outside of a classroom [53], ETs to steer and react to eye movements [13,36], hand-tracking to respond to hand gestures [58], or allowing more immersive experiences, e.g., via head-mounted displays [59] or augmented reality [60]. By recording and examining each movement, one can measure the progress in these games, often automatically and immediately.

SGs can support not only the identification or screening of eye problems, but also training.Current rehabilitation can be boring, due to the requirements to repeat simple movements many times. SGs are used for supporting children's vision training, especially for reading, e.g., via Lexplore [61]. Irazoka and his colleagues present a number of SG tools supporting mild cognitive impairments [62]. This review includes CogPack (http://markersoftware.com/USA/frames.htm (accessed on 15 April 2021)), a computer-based application supporting training, which influenced the programs developed in this study. It incorporates a large number of games, and according to our knowledge, this was one of the first games for vision training, developed in 1986 and still in use.

Other SG-based programs influencing this study are VisionBuilder (https://visionbuilder.com/login/ (accessed on 15 April 2021)), and ReadAlizer (https://www.compevo.se/ (accessed on 15 April 2021)). With VisionBuilder, a user can train saccades, recognition, word reading, stereo vision (with red/blue glasses), mainly to improve reading. ReadAlizer allows measuring reading progress and also promises to help reading. These methods and tools were also developed by including vision experts but are not directly connected to recognizing and treating OMD problems.

Recently, there are some new ET-based solutions available in the market for vision screening or vision therapy e.g., RightEye (https://righteye.com/ (accessed on 15 April 2021)), Clinical eye tracker by Thomson Software Solutions (https://www.thomson-software-solutions.com/clinical-eye-tracker/ (accessed on 15 April 2021)), or Vivid Vision (https://www.seevividly.com/ (accessed on 15 April 2021)). These are expensive solutions for commercial purposes, mainly for clinicians. Vision therapists often use the Computer Orthoptics liquid crystal system to train for vergence, oculomotor skills, and accommodative eye movements [63]. However, this system is an office-based-solution that must be used under the supervision of vision therapists.

3. Study Design

3.1. Methodology

Developing a new and innovative artifact incorporating a number of SGs used for health purposes needs a number of quantitative and qualitative approaches [64]. For this study, the qualitative methods are inspired by the Grounded Design approach defined by Rohde and his colleagues [15], having its roots in Participatory Design [65] and Action Research [66,67]. Grounded Design is applied in case studies for reconstructing "social practices observed before and during the design and appropriation of innovative IT artifacts" (p. 163, [15]). The quantitative method is by adopting the user experience evaluation questionnaire (UEQ) from Schrepp et al. [16].

To design and develop supportive technologies facilitating change processes, i.e., from physical training to SG supported training, involves VTs and computer scientists. Understanding the current situations, suggesting changes, and testing these requires interdisciplinary work. According to the Grounded Design traditions, we consider three important steps:

Step 1. Determining which training can be supported by technologies and how (called pre-study or context study by Rohde et al. [14]). This means finding necessary information about the current vision training (defining the main requirements for the physical vision training today) and which activities can or need to be supported.

Step 2. Finding appropriate prototypes for this support (called working on the artefact by Rohde et al. [14]). This means suggesting changes for practice (through finding and suggesting design solutions for SGs) and improving these (in laboratory settings).

Step 3. Feasibility study—the examination of the appropriateness of the prototypes for actual practices (the part working with the artefact towards building the knowledge based by Rohde et al. [14]). This means esting the prototypes and determining needs and possibilities for the practice in the field. This last part includes a user experience evaluation [15].

The first two steps are based on data from participatory observation during several meetings. Data in the last step are coming from interviews and usability evaluation.

Step 1 was performed during a number of meetings between three VTs and five computer scientists and identified the main eye-movements needed to be trained for OMD problems and discussed if and how SGs could support eye movement for training. For this, the suitability of some earlier games and new existing games were also examined (see Section 4.1).

Step 2 included meetings identifying and improving the six games chosen to support training through four iterations and involved the same three VTs and computer scientists. Each iteration was evaluated by at least one of the three VTs and five computer graphics and games experts. The computer experts involved had earlier experiences from developing the ET-based program, *C&Look* for vision screening [48].

Step 3 presented the evaluation of the final prototype. The results came from a Background Questionnaire (BQ), and user experience questionnaire (UEQ) from [16], and was used to measure user acceptance (data from semistructured interviews). Data came from five VT MSc students in Special Education, with earlier experience in teaching and also in screening and training OMD from their current education (see Section 4.3). The data was collected right after the VT students supported 30 children's vision training, a three-week long training period, without computer-supported training. All the VT students tested the games with technical assistance from a computer scientist (who also participated in Step 1 and Step 2).

The three VTs contributing to finding or designing and developing the games were VTs with several years of experience in their professional area, including using ETs in Norway. The five VT students evaluating the games for training were MSc students in Special Education from Tanzania. Only one of these five students had used ET technology before the evaluation of the games. They filled in the BQ and UEQ by themselves and answered the semistructured interview with questions and discussions about the games' applicability and possible improvements. All participants were female and aged between 30–55.

3.2. Materials

Most of the technologies supporting vision training today are not easily portable, affordable or accessible for children. To keep the prototype portable, the hardware used in the development and testing of this system was a Lenovo Thinkpad T460S Ultrabook™ with a 2.40 GHz Intel Core™ i5 processor, 16 GB of RAM, and a 14-inch multitouch widescreen.

The ET was an EyeX (http://tobiigaming.com/product/tobii-eyex/ (accessed on 15 April 2021)) with a sampling rate of 60 Hz developed by Tobii (https://www.tobii.com/ (accessed on 15 April 2021)), a low-cost commercially available ET (that costs approximately 250 $) that can be used with most commercial laptops. Examples of similar products currently available are laptops with integrated eye-tracking from Acer, Dell, or MSI.

The games were developed in the Unity (https://unity.com/ (much is based on http://response.unity3d.com/games-by-the-numbers-q2-2016-report, accessed on 15 April 2021)) game engine using the programming language C#, and applying the EyeX and the C# "Gaze API" provided by Tobii. Unity also features out-of-the-box physics, making it easy to create 2D or 3D objects that act naturally in the applied environment. Since the OMD training application consists of several small games, there is essentially one application for each game connected through Unity's scene management, allowing the user to transition between games smoothly.

Before usage, the eye tracker had to be calibrated to fit a user's head and eyes. This calibration was implemented in the application through the Gaze API. A user calibrated her eyes by looking at three points for 2 s, one after the other. After a point disappeared, the calibration was performed for that specific area. The calibration time lasted a few minutes (3–5 min). The interaction with the games was performed using eye gaze and pushing some keys on the keyboard.

4. Results

4.1. How Can Children with OMD Train Their Eyes Eoday? (Step 1)

There is no generally accepted set of guidelines supporting training programs for children who struggle with OMD.

The most commonly recognized eye motoric challenges (also described in Section 2), the activities they trigger and the physical exercises needed to perform the challenge are described in Table 1, which was built on the suggestion from a vision teacher included in our group [34]. The first three columns in the table illustrate the identified important movements the trainee needs to perform with her eyes to strengthen her visual abilities.The exercises seen in Table 1 are all broad in the sense that one can train more than just one specific ocular muscle movement with each exercise. For example, practicing "Searching/scanning" may train both fixations, endurance, saccades, and mini saccades, depending on how the exercise is performed. Since elements in the vision system are interconnected, one challenge has multiple terms connected to it and several exercises. However, it is necessary to be aware of the fact that children can be stressed and exhausted, and a trainee can also be overloaded if this is done without professional competence.

Visual efficiency disorders are classified into accommodative disorders, binocular vision disorders, amblyopia, and ocular motility disorders [68]. Ocular motility disorders are problems with eye movements such as fixations, saccades, and smooth pursuit [69]. After this identification, the primary mission was to choose games that systematically trigger eye movements to perform exercises needed to support the ocular motor activities from Table 1.

Table 1. Training of eye motoric challenges by activities with different exercises.

Challenge	Ocular Motor Activities	Exercises
Field of view	Saccades Visual attention Regression	Horizontal movements Vertical movements Diagonal movements Circular movements
Visual acuity	Fixations Endurance Saccades Mini saccades	Searching/scanning Find objects in a crowd Horizontal movements Vertical movements Diagonal movements Circular movements Smooth pursuit Find pairs/similarities Trace the eyes through a labyrint
Stereopsis	Accommodations Convergence Double vision	Movements and flashes at a distance—different depths Objects that varies in size
Eye-hand coordination		Use the mouse or keyboard-based on events on the screen, and vice versa.

Since "Field of vision" and "Visual acuity" are broad fields, different games were required to complement each other to cover all movements which need to be performed during the training.

Stereopsis was not a priority in this game because it is hard to simulate animations that could complement accommodations or convergence eye movements on a computer screen. This could be addressed in a future version using an HMD device with integrated eye and hand tracking.

4.2. Finding, Designing, Developing, and Adjusting Games (Step 2)

4.2.1. Earlier Programs Influencing This Study

Several existing games were investigated to design games for the required exercises (see column 3 from Table 1). These were, first of all, games available from Tobii, or VisionBuilder (mentioned earlier). Cocos2D (http://cocos2d.org/ (accessed on 15 April 2021)) was also considered for this project. However, the code was considered out of date and therefore hard to maintain and develop further. The main problem with Cocos2D was its lack of information about integrating other softwares, and the fact that it had a less comprehensive graphical workflow can make the development process slower. While Tobii provides a low-level C++ SDK that was easier used with Tobii's ET, this was chosen for this project. The games available and possible from Cocos2D but without ET support were also considered more advanced than necessary for this project, having the baseline the games from CogPack.

As we pointed out earlier, there are some existing computer-based applications supporting training. The games that most influenced the development are within the package of 64 games offered by CoGPack. Examining these existing games and having the requirements for exercises presented in Table 1, the VTs identified some more needs the new games should satisfy for covering OMD problems of different severities:

- high screen contrasts,
- usable for color-blind people,
- possible to control object speed by eyes, and
- possible to change the background color(s).

During the four iterations of development, several other properties of the graphical interfaces were discussed with designers and vision teachers. Examples are:

- the possibility to use on-screen documents

- have challenging and adjustable-sized images for different vision impairements
- that both video and audio should be supported (important for reading)
- that both 2D and 3D graphics should be supported.

Younger children who cannot read can be screened and trained by using graphical images and adjusting its sizes to fit individual problems. These requirements are coming from lessons from experiences from an earlier version of ReadAlizer that could only be used for children who could read texts. The VTs believed in using more graphics, except 3D graphics, at this stage. Several of the identified properties were implemented during the development. After examining additional games, including the ones available through the eye-tracker providers, and CogPack six games (presented in the next Section) were chosen for this study.

4.2.2. Games Triggering Desired Eye Movements

The games were designed and improved based on Table 1 to cover most of the necessary ocular motor activities. Improvement on game design, such as adjusting representations, speed, colors, levels and time to play, were done through four iterations. The software and graphics were improved based on the VTs' experiences regarding images, colors, and movements. First of all, these requirements were adjusted to fit a child's capabilities with a medium-level OMD problem, which is not necessarily an observable vision impairment. These improvements were made during four meetings with programmers and VTs.

The reason for adjusting the settings in each game, e.g., the size, colors, and type of the letters, objects sizes, their spedd and visibility on the screen, number of focus points, was to connect the game difficulty level to the children's capability and considering her vision imediments. The levels must fit each child's problem and it must be possible to adjust the difficulty in games as children learn, or as their vision capabilities improve. Before evaluating the functional prototypes, the three VTs mapped the games' challenges and activities to the challenges identified for physical training described in the first and second columns of Table 1.

4.2.3. The Games

Game 1: Compare Words

In this game, the user has to look at two similar words and find (and mark) if these words are identical or different. It is inspired by one of the games in CogPack. To identify differences, the user must perform saccades between the words and micro-saccades while studying the single words. The exercise trains both reading, big saccades, and the brain's ability to identify the content. The games can be adjusted with respect to the difficulty of the words, the letter sizes, colors, the language, and the game duration. The number of correct choices for recognizing the same and different words can be seen in the left corner (see Figure 5a).

Game 2: Maze

The second game's goal is to allow the user to navigate through a maze back and forth with her own gaze without hitting the maze walls (see Figure 5b). After every successful navigation, the user earns one point. The educators could spot the difference in gaze position between the right and the left eyes during the game. This game trains the smooth pursuit, i.e., the ability to follow a path with the gaze and keeps the attention on the road while avoiding obstacles.

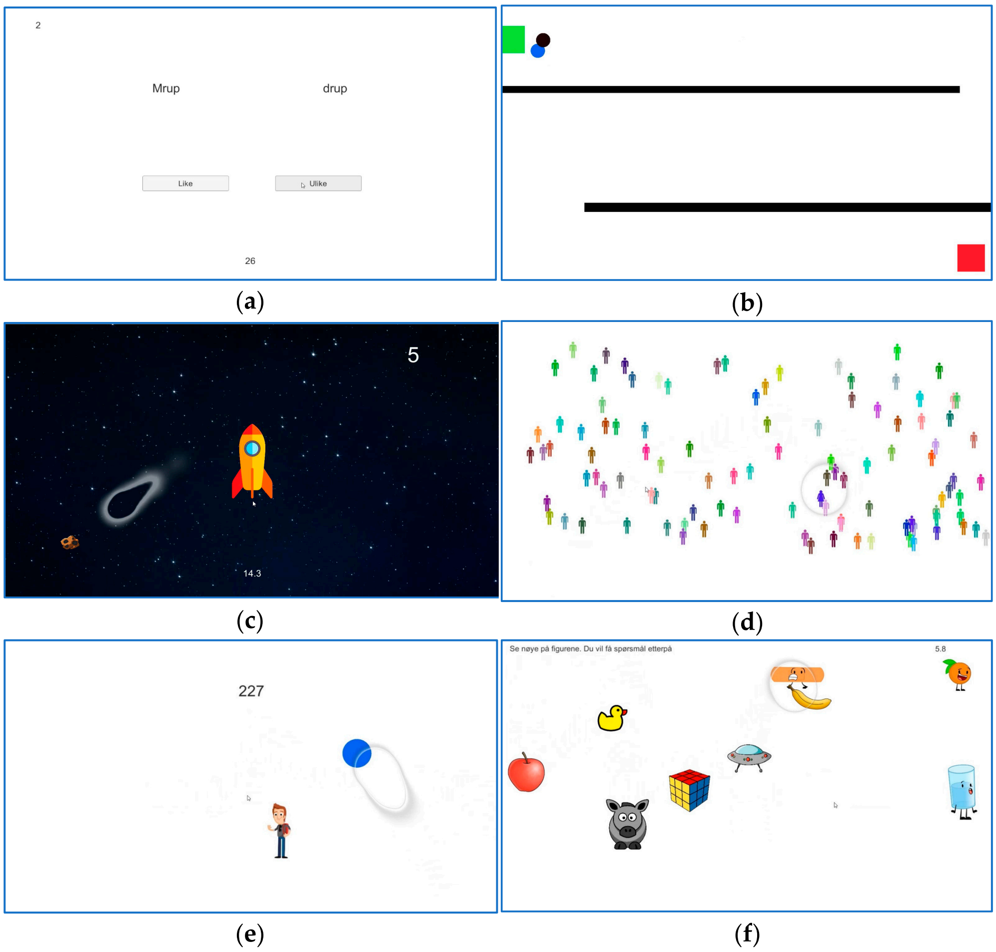


Figure 5. Screenshots from the games: (**a**) Compare words, with the number of correct choices in the top left corner; (**b**) Maze; (**c**) Save the rocket; (**d**) Find the outstanding object; (**e**) Follow the ball; (**f**) Which one is missing?

Game 3: Save the Rocket

In this game, a user needs to save a rocket located in the center of the screen from meteors (see Figure 5c). The meteors fly in from the edge of the screen and are eliminated by fixing the gaze at it. If any meteor hits the rocket before the time runs out, the user has failed. The supervisor can set the difficulty level by adjusting the game duration, the number of meteors, and their speed. This game is chosen for training visual attention and continuous performance of saccades.

Game 4: Find the Outstanding Object

The fourth game includes several objects on the screen, and one of them is different from the others (see Figure 5d). The goal is to find this object and fix the gaze at it for a couple of seconds. This game is much like the game Where is Waldo, with ET input. In this game, it is possible to change the difficulty level by changing the number of distractor objects. It is also possible to choose the types of figures that are shown. The game counts how many seconds the user needed to find the object. Like the game from Figure 5c, this game also trains visual attention. The difference is that the stress level of the environment can be varied by the number of distractions, and also by giving the user more or less time to think and process all the presented objects. The user must continuously perform saccades to move their gaze between the objects, and fixations for analyzing a specific one. Besides, the user needs to utilize the peripheral vision to find interesting areas to look towards.

Game 5: Follow the Ball

In this game, the user needs to follow a ball that moves smoothly across the screen (see Figure 5e). When the user's gaze is pointed at the object, the score increases. Distractions appear at random places on the screen, but the user should ignore that and keep looking at the chosen moving object. This game runs until a defined number of points is gained. It trains smooth pursuit movement and the ability to control the fixation during distractions.

Game 6: Which One is Missing?

The last game is a memory game where the user looks at several objects in the first screen. In the next screen, one of theobjects is missing. Then the user must find and pick with their gaze the extra object in the second screen (see Figure 5f for a first screen). When the missing object is found, the user must move it onto a square using their gaze, and press the space button to release it. If this object was the correct one, the level is completed. This game trains visual memory, visual attention, and saccades. When the user is looking at the various objects, the eyes are continually performing saccades.

4.2.4. Connecting the Games to Necessary Eye Movements

Figure 5 presents the last iteration (for a typical screenshot) of the games. They were chosen from a large number of games [70] fulfilling these criteria: suitable for training, possible to use them on portable devices (laptops), suitable for use by affordable eye trackers.. The main criterion was that they would be suitable for training for OMD children.

Table 2 includes the rationale behind the games via the correspondence between Column 2 (what has to be trained) and Column 3 (via which eye movements), and Column 4 (what are the games triggering these eye movements). These correspondences were discussed and games were selected during several meetings with the three VTs involved in the design during a 3–4 month long period, approximately for 1–2 h long meetings with at least one VT involved per week.

Table 2. Training of eye motoric challenges by activities with different exercises. The last column (Game) is for Step 2, synthetizing the opinions of VTs, e.g., which games are complementing the challenge and ocular motor activities. See game numbering in Figure 5.

Challenge	Ocular Motor Activities	Exercises	Game No
Field of view	Saccades Visual attention Regression	Horizontal movements Vertical movements Diagonal movements Circular movements	1, 2, 3, 4, 6 2, 3, 4, 6 2, 3, 4, 6 3, 4
Visual acuity	Fixations Endurance Saccades Mini saccades	Searching/scanning Find objects in a crowd Horizontal movements Vertical movements Diagonal movements Circular movements Smooth pursuit Find pairs/similarities Labyrinths point to point	4, 6 4 1, 2, 3, 4, 6 2, 3, 4, 6 2, 3, 4, 6 3, 4 5 1 2
Stereopsis	Accommodations Convergence Double vision	Movements and flashes at a distance—different depths Objects that varies in size	None
Eye-hand coordination		Use the mouse or keyboard-based on events on the screen, and vice versa.	1, 6

4.3. Evaluating the Feasibility of SG Prototypes for Vision Training (Step 3)

4.3.1. Results from the User Experience Questionnaire (UEQ)

Table 3 presents the UEQ, with in total 25 aspects to rate. These are examining different aspects of the game ranked from 1 to 7 based on their experience, where 1 was the lowest (most negative), and 7 was the best (most positive) [17]. The respondents were told to put a cross in the circle that represented their answer.

The questions are grouped in three groups and evaluated via four questions for each property:

1. attractiveness
   - via enjoyable, good, pleasing, pleasant, attractive, and friendly.
2. design quality
   - via stimulation, valuable, exiting, interesting, motivating,
   - via novelty, creative, inventive, leading-edge, innovative.
3. use quality
   - via efficiency, fast, efficient, practical, organized,
   - via perspicuity, understandable, easy to learn, easy, clear,
   - via dependability, predictable, supportive, secure, meets expectations.

The results mirror some of the actual situations, i.e., that the attractiveness of the games is appreciated. While the innovativeness or certain design aspects are not appreciated equally high, the use quality is recognized.

It is challenging to run statistics based on only five participants, so responses have to be treated carefully.

Table 3. Answers for the UEQ for all games. The evaluation is done after playing the games.

	1	2	3	4	5	6	7		Mean
annoying	○	○	○	○	●	○	○	enjoyable	5.25
not understandable	○	○	○	●	○	○	○	understandable	3.75
dull	○	○	○	●	○	○	○	creative	4
difficult to learn	○	○	○	●	○	○	○	easy to learn	4.5
inferior	○	○	○	○	●	○	○	valuable	5.34
boring	○	○	○	○	○	●	○	exciting	5.5
not interesting	○	○	○	○	●	○	○	interesting	5.25
unpredictable	○	○	○	○	●	○	○	predictable	4.75
fast	○	○	○	●	○	○	○	slow	3.5
inventive	○	○	○	●	○	○	○	conventional	4
obstructive	○	○	○	○	○	●	○	supportive	5.5
bad	○	○	○	○	○	●	○	good	5.75
complicated	○	○	○	●	○	○	○	easy	4.25
unlikable	○	○	○	○	●	○	○	pleasing	5.25
usual	○	○	○	●	○	○	○	leading-edge	4
unpleasant	○	○	○	○	○	●	○	pleasant	6.75
not secure	○	○	○	○	○	●	○	secure	6
demotivating	○	○	○	○	●	○	○	motivating	5.5
does not meet expectations	○	○	○	○	●	○	○	meets expectations	5.25
inefficient	○	○	○	○	○	●	○	efficient	5.75
confusing	○	○	○	●	○	○	○	clear	4
impractical	○	○	○	○	○	●	○	practical	5.75
cluttered	○	○	○	○	○	●	○	organized	5.75
unattractive	○	○	○	○	○	●	○	attractive	5.75
unfriendly	○	○	○	○	○	●	○	friendly	5.75

4.3.2. Answers after Semistructured Interviews

The VT students' first impressions of the games were positive. Answering the question if they would like to use it in their daily work, all, except one, answered yes. The motivation for the "no" was that the game is "*not self-instructing today*." Those who wish to use it also expressed their wishes to have time to find out more about how the games complement the training.

Opinions on Using Games to Support Vision Training

Answering the question "What would make use of games more supportive", two VTs expressed their wish "*to have some instructions from the beginning, both for the trainee and the instructor.*"

Discussing opinions for trainees versus instructors, the VTs expressed that the games are "*good for the kids, and they can better understand them* [than instructions for physical exercises, in general]."

One expressed her wish to be able to better adjust the levels in the games to the participants, their age, preferences, and vision impairment. Some games were quite hard to follow, even for those with not severe OMD (Game 2, the Maze, and Game 6, Which one is missing).

VTs expressed their wish to better understand games and their concrete benefit for OMD training. They wished to have some categorization or interface helping the teachers choose and adjust the right games for the expected treatment. An example of this was Game 5 (Follow the ball), as one of the participants noted: "[While this would be a] *good exercise for smooth pursuit movement, it is not completely clear. Maybe you can make different levels of difficulty with different speeds and sizes or colors of the ball? Unsure about the usefulness of the appearing person. Is it actually for concentration or the vision* [attention]?"

General Usability

The participants estimated all games as usable in relation to the general usability of objects on the screen (information placement, sizes, colors, etc.). Still, they suggested improvements, especially for Game 2 (the Maze).

They commented on the colors, the speed, and the way that one can progress in the games. For representing the results on the screen, i.e., for Game 3 "Save the rocket", they believed the number illustrating the scores takes too much attention. Perhaps a number showing the time spent with the game might be useful.

Only one of the VT students thought that training with ET-based games could replace physical vision training today, but all participants believe that games have an important place in training and rehabilitation and have a great potential to complement VTs work. The special pedagogy education they follow does not include computer courses, but they think they would manage to handle the games after an easy setup. They do not express any doubts that trainees can learn the games easily, but they could not imagine, at the present state, how trainees could use it by themselves at the beginning.

The VTs like games without many objects on the screen, and they wished to have more contrast. As a VT student expressed, "*For me, it was too low contrasts, even with the calibration dots in the beginning. These should also be bigger*."

Concerning the screen size (playing the games on laptop computers), they believe that a larger screen can allow much more training. However, they also wished to have such supporting games on mobile phones in the future.

Overall Experiences of Possible Use and Improvements of the Game

Game 1 (Word differences) was quite outdated, similar to one of the games from Cog-Pack, but "*a good exercise for left-right saccades and fast reading*." Some further development suggestions were to make the game run for x words instead of x seconds and count seconds instead. This would be a better way to track progress. It should also be possible to choose the words' background and position to cover up-down and diagonal saccades.

Game 2 (Maze) was too hard and should be made much easier by making the walls shorter with a longer distance. Apart from that, the game is a good way of training to navigate the eyes through a road avoiding obstacles. One feature that was discussed in this game was initially a bug; when one eye is closed, the user could use the other eye to push the ball through the maze. This could have been a fun element and a new challenge to implement. In this game, it would be good that the VT could see the position of the user's eyes at all times. This may also contribute to the detection of problems during the training.

Game 3 (Save the rocket) This game is very similar to another CogPack game where the user should eliminate incoming shots in a box. The new thing here is that this game features ET and has better graphics. One way of improving this game could be to give a different amount of points per exploding meteor according to how far away from the rocket the meteor is. This would encourage more "searching" and less waiting in the middle. The game could also feature different types of elements instead of only a rocket and meteors, or the contrasts could vary. Apart from that, the game is considered supportive for training saccades and for visual attention by forcing the user to search around the screen. Another suggested improvement regarding these games was to apply a touch screen, where the user had to touch the meteors to eliminate them and examine eye-hand coordination.

Game 4 (Find the outstanding object) could be a replacement for different types of books used in training today. It is very straightforward and fits people of all ages. The game trains saccades between objects as intended, both left-right, up-down, and diagonal. For improvement, it would be nice to be able to choose where in the screen the objects should appear, the spread, and adjust the levels for possible improvements.

Game 5 (Follow the ball) should have more settings. One way is for instance to remove the distraction for the easy levels and maybe add more distractions for the harder levels. One could also vary the size of the ball according to the level of difficulty. The ball could also have a more defined movement. Instead of the current solution, the progress could be measured by the number of points achieved during a limited time. Apart from this, the game is good training for smooth pursuit movements.

Game 6 (Which one is missing?) This game was experienced as too difficult because many objects need to be remembered. It should be possible to choose the level of difficulty and maybe have increasing difficulty for each round. In this game, the space bar is used to pick up items. Maybe blinking to pick up objects can contribute to another layer of difficulty? The game is good training for visual memory and saccades and could be used in training.

Overall Experiences of the Games

The VT students were enthusiastic, liked the games, and stated that they were better than existing computerized solutions, but that at the present stage, they cannot fully replace expert-assisted physical training. The main reasons are the limited size of computer screens for peripheral vision training and the lack of possibilities to support depth-training. This was true for all the games. Another reason is the missing overview to see the effect of the training effect, or exactly what is happening during a game, e.g., the visual information on the screen and the eye movements associated with some measures about the movements. Two of the VT students noted that it would be interesting to look at different methods to make the game experience even more enjoyable as some of the exercises were somewhat monotonous.

5. Discussion and Future Work

Vision training, as most training for rehabilitation purposes, takes time. With a large number of trainees, which there are according to the statistics [3,27], it would be essential if a part of this training could be performed without using more expert resources than necessary. However, it is a long way ahead to substantial digitally assisted training, and expert participation is still critical. There are also hypotheses that schools and general teachers could help and take a more significant role in such training [4,12,13]. At the present moment, the VTs role is also essential. They need to determine the training process and design improvement goals; however, it is not necessarily that they need to support the entire rehabilitation process.

This study investigated the feasibility of SG prototypes. On the way to develop a working product, several aspects can be considered, but probably the most important is to define enablers for utilizing the technologies. In the following parts it is discussed how this can be possible in a more general term.

5.1. Understanding the Whole Process via Interventions and Rehabilitation

Today screening and training are separate activities, which may be connected to enable children-centric vision care. For helping children with OMD problems many of the actors involved in screening and training are the same, but there are also separate actors, and they should know about the data that are related to the whole process. Ultimately, it would be valuable to contribute to creating tools that foster more children-centric vision care, where much of the training activities could be performed at home, and e.g., progress could be followed by experts.

Screening may also benefit from game-based methods, as this activity is often perceived as boring for children in clinical settings [46], and some children find it hard to sit still during screening. If the screening process could be made more interesting by applying more game elements, this could improve data quality and make screening more accessible. The software also needs to be further developed to better illustrate the connections between exercises, the functional vision, and the effect of training.

5.2. Supporting Technologies: Understand What to Complement and How

The sensemaking process (*Step 1* and *Step 2* for understanding rehabilitation goals and methods and technologies) is crucial for knowledgeable vision experts to understand technologies' possibilities and define basic requirements for developing technologies. The cooperation with the vision expertise during the development of the game was highly appreciated. Eventually, this shared understanding can be supported by process steering instruments, e.g., Design Thinking.

As we pointed out earlier, a critical aspect is to investigate to what extent game-based training can complement the current training methods. Since depth vision in games is not possible at the present stage, and peripheral vision is limited in the present games, these training exercises have to be supported by physical exercises. With the development of immersive technologies and applications, such training may be possible. There can be better possibilities to use HMDs for short and long-distance or peripheral vision training. However, for this the HMD technology and handling graphics in HMDs also needs to be improved. However, there are already some examples. Nowak and his colleagues [44] showed the potential of using HoloLens (a see-through HMD using physical space and virtual images) for the rehabilitation of amblyopia (lazy eye) in children, and Ziak et al. [45] used HMD's for adults.

5.3. Enablers (for Using Technologies)—Are Not Necessarily the Users

One of the main benefits of starting this project was realizing that the enablers for using the technologies are vision experts. Their opinions is not only important for their expertise with handling vision difficulties but also their willingness and competencies for handling the technologies.Their user experiences may differ from the end-user's (the children's) wishes for games but necessary fo accepting the games for rehabilitation tools. The evaluation with children will probably determine more requirements on game challenges, attractive images, and ways to increase user experiences and presence to sit in front of a computer and train their eyes.

5.4. Possibilities for Developing Future Games

Since literature demonstrates that positive results can be achieved already after 3–6 week vision training, different new possibilities to make this training need to be investigated. One option is to understand whether it is possible to perform parts of the training alone or be supported by nonprofessionals, and also better understand the role of the professionals and how they can be involved.

Vision screening using ET produces *measurable*, objective results and is a valuable tool for identifying OMD. When training is performed, this method can also be used to evaluate progress. Today screening and training are separate activities and are done by using screening and training software packages separately. However, by integrating evaluation into the games-based training software, using ET technology, it is possible to create training software where the user may perform training and assess progress, potentially without continuous professional support and supervision (see above). At the very first step we develop measurement methods for the necessary aspects from Tables 1 and 2 regarding OMD activities for the suggested games.

Having an OMD screening program in the background will allow measuring the progress automatically and immediately. We have made use of affordable ET hardware, and our goal is to make the software open source. This contrasts with existing computerized solutions for OMD, which to our knowledge, uses proprietary software and expensive ET hardware. One of the main motivations behind this is the intention to make the programs usable for many. The possibilities to access data from many users mean that AI algorithms can identify and develop more supportive training solutions.

6. Conclusions

This project has shown the design of a prototype system for vision training with three VTs, which has been tested by five other VT students, evaluating several aspects of its quality and usefulness with the main qualities to trigger the same eye movements as the necessary eye movements with today's non computer supported vision training.

By this the study shows the possibility of integrating computer games into the vision rehabilitation process from the VTs perspective, by considering concrete rehabilitation goals and designing games to find measurable aspects supporting training and training fulfillment. Based on guidelines for creating a training program for children who struggle with OMD, we have created a collection of exercises based movements implemented in six computer games and evaluated them by Norwegian and Tanzanian vision experts and found and presented a number of issues needed to be taken in consideration for further development and acceptability for supporting rehabilitation.

Another benefit of this study can be the interdisciplinary approach it follows. While several stakeholders from different domains are involved in developing games for rehabilitation, this is a long and complex process, requiring intense collaboration for translating goals from one domain into goals in another domain. While the results are only partial, they have to be discussed within the scientific community. For this process, we consider Grounded Design helpful.

Author Contributions: Conceptualization, I.H., C.H., and D.P.; methodology, I.H.; software, H.P. and A.B.G.; validation, H.P., I.H. and A.B.G.; formal analysis, I.H. and Q.A.; investigation, I.H., C.H.; resources, I.H. and C.H.; data curation, H.P. and C.H.; writing—original draft preparation, I.H.; writing—review and editing, I.H., C.H., D.P. and Q.A.; visualization, I.H., A.B.G. and H.P.; supervision, I.H. and C.H.; project administration, I.H.; funding acquisition, I.H and C.H. All authors have read and agreed to the published version of the manuscript.

Funding: This paper is financed by the Vision 2030 project, Securing education for children in Tanzania. Funding N.F.R., Project no: 267524/H30.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: Thanks to the vision teachers and educators Gunvor Birkeland Wilhelmsen, Tina Ihler, Heidi Jåstad, and our colleagues Harald Soleim, Mads Gjerstad Eide, Ruben Watanabe. Much of this paper is based on the MSc works of Håvard Homme Pettersen (HP) on vision training [70] and Mads Gjerstad Eide and Ruben Watanabe on vision screening [48].

Conflicts of Interest: The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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Article

MyDiabetes—The Gamified Application for Diabetes Self-Management and Care

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Abstract: Gamified applications are regarded as useful for patients in facilitating daily self-care management and the personalization of health monitoring. This paper reports the development of a gamified application by considering a design that had previously been investigated and reported. Numerous game elements were installed in the application, which covered several tasks aimed at managing diabetes mellitus. The development process utilized the Rapid Application Development (RAD) methodology in terms of system requirements, user design, construction, and cutover; this paper refers to the user design and cutover processes. The developed application was tested through system testing and usability testing. The usability testing adopted the Software Usability Scale (SUS) to assess the usability of the application. Twenty participants were involved in the testing. The result showed that the gamified application is easy and practical to use for an individual with or without diabetes. All the provided functions worked as designed and planned, and the participants accepted their usability. Overall, this study offers a promising result that could lead to real-life implementation.

Keywords: gamification; diabetes self-management; RAD methodology; game-design-based; Software Usability Scale

Citation: Tuah, N.M.; Yoag, A.; Ahmedy, F. MyDiabetes—The Gamified Application for Diabetes Self-Management and Care. *Computers* **2021**, *10*, 50. https://doi.org/10.3390/computers10040050

Academic Editors: Paolo Bellavista and Carlos Vaz de Carvalho

Received: 28 February 2021
Accepted: 9 April 2021
Published: 13 April 2021

1. Introduction

Patients with long-term health conditions must adapt to a new routines and lifestyles, mainly involving their daily activities and dietary intake. Recent technology has revolutionized such activities by creating incredible tools and resources, and putting useful information at our fingertips. Despite the growing prevalence of smartphones, health-focused digital learning using the gamification approach has only been sparsely implemented in daily life. This omission may hinder an individual's efforts to self-care and manage, particularly those living with health conditions like diabetes mellitus.

Diabetes mellitus (DM) is one of the most common non-communicable diseases worldwide. It has become an important item on the agenda of healthcare providers. In recent years, researchers have focused on developing intervention tools that can foster self-care management. Unmanageable levels of blood glucose led to health complications and a decline in quality of life.

DM is an endocrine disease characterized by a person's blood glucose level [1,2]. A significant increase above the normal level will lead to a diagnosis of type 1 or type 2 diabetes mellitus. Healthcare services should promote the awareness of a healthy lifestyle and disseminate diabetic literacy and knowledge widely to prevent the condition from increasing. In Malaysia, DM has been increasing annually; a particular issue is the rise in Type 2 DM among Malaysian adults over 30 years old [2,3]. This increment is due to poor self-care management, minimal awareness of the disease, a lack of medication adherence, and dietary issues [2]. Individuals with DM require careful monitoring and care from the patients themselves, the primary care clinic, and the hospital. Currently, healthcare providers utilize readiness questionnaires [2] to test individuals' knowledge and literacy of their condition, the related treatment, and the care required.

Meanwhile, game-related research scholars have recognized gamification as an approach that uses game mechanics in non-gaming contexts to facilitate healthcare management [4]. The gamification approach offers an attractive application that could encourage and help individuals understand and become informed about their condition. Gamification helps to balance learning and playful aspects while maintaining conditions of good health. In general, healthcare and gamification have been integrated and implemented in various diabetes applications. Gamification is seen as an approach with much potential in the healthcare field. Scholars have investigated gamification as a practical intervention tool for motivating individual engagement with treatment and care [4–6]. Moreover, for individual patients to learn about their condition through a playful environment is considered more convenient for them, and the prevalence of such environments will increase via mobile devices.

Research in gamification and healthcare has frequently been explored to provide viable options to patients and healthcare providers in facilitating diabetes self-care management. Previous research [7] showed no significant improvement in patients' medication adherence when using games for DM. Another study [8] has reported that using games for DM has no considerable effect on HbA1c reading. However, there was a significant result in terms of diabetes knowledge and awareness. Since then, researchers have studied and improved many aspects of this intervention, especially in the gamification and understanding of self-care. Previous research [1] has recommended the need for an effective platform, standardization, and simplification to ensure better knowledge acquisition.

Although the research on self-care management through fun learning games and gamification has been conducted, these studies only focus on a single diabetes issue, for example, problems of blood glucose [8], medication intake [7], and diet management [5]. Furthermore, the available applications (mention by, for example [9,10]) have existed in different platforms and environments, but some are quite expensive due to the need for external devices. In addition, more configurations are needed for these devices, leading to the disruption of the process of learning about self-care management. Additionally, diabetes self-management using mobile applications is seen as not sufficient, whereby the features of self-management in a mobile app are very limited and do not comprehensively cover the diabetes requirement [11,12]. Developing one platform that integrates several issues related to DM would enable a practical and convenient tool for knowledge acquisition and self-care management.

This paper presents the groundwork for developing a playful, integrated environment and gamification application for DM. This development stage is a continuation of the requirement stage that was reported previously in [6]. The development process is described, and the results from the system testing are presented. The developed gamified application in this paper is intended to contribute to enhancing a self-management and self-care platform with gamification and a fun learning environment. Most importantly, the report discusses users' access, pace, time commitment, and capability in terms of managing their own health condition.

This paper is organized as follows: first, this paper reviews works related to DM; then, it describes the materials and methods used in the study. The description of materials and methods includes the development methodologies, the gamified applications, and the testing procedures. The next section covers the presentation of the results and discussion based on the conducted system testing. Finally, the concluding remarks as well as recommendations for future work are presented in the last section.

2. Related Work

Following the framework of diabetes self-management by Al-Marshedi et al. [13], the component of self-management requires a logbook, data visualization, and trend alerts. A logbook can incorporate medication tracking, appointment tracking, and a log of every task related to a patient's condition. The application summarizes these logs into a simple visualization chart/graph. The chart provides the resultant trends, with any unusual trends alerting the patient, carers, and doctors if the system is connected to them. Moreover, the self-management of diabetes is enhanced through educational games, apps monitoring, and in-game motivational feedback [9,10]. Included in the self-management functions of most mobile apps on the market, as reviewed by Priesterroth et al. [10], are the functions of a diary for insulin doses, and logs of food intake, activity, weight, and blood pressure. The reviewed articles researched these functions utilizing fun learning games and gamification over the years. However, those articles only focus on a single diabetes issue, for example, problems of blood glucose [8,9], medication intake [7], and diet management [5,14].

Research by Klaassen et al. [9] and Lewis et al. [15] use the PERGAMON framework, which utilizes wearable sensors, games, and gamification for their diabetes self-management application. The framework is designed as a gamification platform. It has many functions, such as a diary, mini-games, user profiles, and personalization. It uses a virtual coach, goals, and tasks as the main game elements, apart from points, badges, and levels. The game mainly involves empowering patients with the knowledge of controlling blood sugar levels through their dietary intake and carbohydrate counting tasks. Patients can also log any activities related to diabetes through the application, for example, exercise activities and daily water intake. Furthermore, the application allows the patients to create and customize their profiles. Nevertheless, these applications require external devices to be paired with the application.

In terms of the application of gamification for diabetes, Klaassen et al. [9] discussed the difficulty and complexity of diabetes games that are suitable for self-learning. They must be designed to be straightforward and simple. Moreover, the design of the games and applications must be aligned with the targeted users. Vassilakis et al. [16] further emphasized that in diabetes self-management, learning through digital applications or games is an alternative method used by healthcare personnel to support and motivate a patient to enhance their level of learning. In this view, giving feedback and guidance are essential, and ease of use should be considered in the design of applications. Other than using a gamified platform application, the literature reports that applications that are solely games have been utilized as tools to educate diabetes patients (such as [5,8,16]). Even though such applications have a specifically targeted diabetes solution, they are designed and built with multiple activities that facilitate the acquisition of the knowledge and skills related to diabetes. However, various aspects of diabetes knowledge and the scope of the related skills have yet to be discovered, and further research should be expanded to include diabetes-specific features. Vassilakis et al. [16] suggested that more games should be designed to educate patients in various aspects of diabetes, including the promotion of a healthy lifestyle, the need to avoid smoking, and encouragement to take up physical activities. Moreover, as reviewed by Priesterroth et al. [10], the gamified applications have frequently been implemented to promote self-management. However, gamification features are not systematically implemented in such applications.

Meanwhile, Brzan et al. [12], in their review of the 65 mobile apps for diabetes self-management, argued that the mobile apps development should employ user-centered design, which will specifically include individual patient's requirement in the application. The review also showed that only a small amount of content related to learning and self-management was embedded in mobile applications. The self-management indications used in [12] include monitoring blood glucose, nutrition intake, physical exercises, and body weight. However, it should not be limited to those functions only. Other self-management features suggested in [12], such as reminders, notes, tracking functions, and personal messaging, should be designed and applied in the mobile application. One particular issue in mobile apps implementation that should be considered is the feature of diabetes self-management in mobile apps is limited [11,12]. Huang et al. [11] advocate that many diabetes mobile apps lacked medication management features and had less emphasis on basic reminder features. Thus, designing the self-management components is crucial and needs to carefully consider the requirement for diabetes and the requirement from patients.

Therefore, even though the available intervention tools utilizing gamification elements have been researched and invented, they represent different targets in improving a person's health condition. As self-management and care are the keys to health improvement, features related to these aspects must be designed accordingly. Thorough approaches to the design and implementation of gamification tailored to diabetes self-management requirements are needed to produce a more practical intervention tool.

3. Materials and Methods

This section focuses on the methodology and materials used in building the gamified application. A stepwise explanation of the processes involved in each phase is presented. Likewise, the materials employed are also described; those involved in this study are (1) the tools utilized in the development phase and (2) the gamified application itself. Moreover, this section outlines the gamification features and the implementation of the gamified application features.

3.1. RAD Methodology

The development of integrated playful games for diabetes mellitus follows the Rapid Application Development (RAD) methodology. RAD consists of 4 phases: requirement planning, user design, construction, and cutover. RAD is a method that focuses on system development through a prototype and reusable codes. Using the prototype, developers can obtain rapid responses from users during the development cycles. Meanwhile, the reusable codes from available open-source repositories enable the development period to be shortened. Moreover, this method accelerates the development period without impairing the quality of the application. Thus, RAD was chosen on the basis that developers and users work synchronously to create a functional product that follows the user's requirements. The RAD phases are presented in Figure 1.

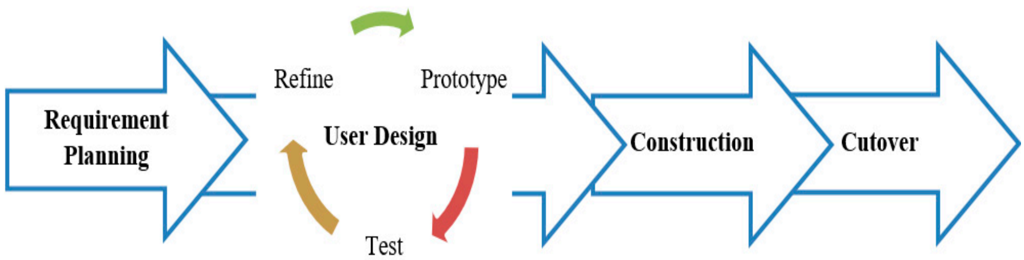


Figure 1. Rapid Application Development (RAD) methodology.

Based on the RAD methodology in Figure 1, each phase is described as follows:

(1) Requirement Planning phase: The requirements of a system are gathered and analyzed by the developer, after which a response from the users is received to confirm the requirement specifications. In this study, research previously conducted by the authors gathered the users' requirements through a user experiences approach. The authors implemented mock-up applications and storyboards to present the design ideas. This process involved a group of users from whom the researchers obtained their requirements through a focus group discussion. The results from the discussion were translated into a low-fidelity prototype, for which confirmation was sought from the users.

(2) User Design phase: The confirmed requirements from the previous phase are processed further by the designer or developers. Generally, this phase involves the iterative process of a detailed system design. Following the detailed design, a prototype is developed, tested, and refined based on the users' quick responses. In the context of this study, the authors created a high-fidelity prototype and obtained responses from the users to gain final confirmation of the design from the previous

phase. Then, the approved design was transformed into a complete system in the construction phase.

(3) Construction phase: Then, the high-fidelity prototype from the previous phase is improved into a fully developed system. In this phase, the essential aspects—the functions, interfaces, and databases—are integrated and completed. In the context of this study, the authors developed and tested the gamified application. The developed application was created with full system functionality, interfaces, and the integration of complete databases. Details of the game development approach are presented in Section 3.3, and the testing method is outlined in Section 3.5.

(4) Cutover phase: In this phase, the functions, interfaces, and databases are confirmed as a final system. In the context of this study, the authors conducted system testing to certify that the system worked as designed and required by the users.

Following the RAD methodology, phases 1 and 2 were successfully conducted and published, and this paper reports the work related to phases 3 and 4. The system's construction is presented in Section 3.3, and the system testing in the cutover phase is presented in Section 3.5.

3.2. The Development Tool

The diabetes gamified application in this study was developed using the PHP framework. The developers used the PHP code in coding the applications, the CSS for the interfaces, the JSON and JavaScript for the gamification element, and phpMyAdmin for the database. Hostinger.my was subscribed to as the server and hosting platform.

3.3. The Gamification Design and Development Approach

In developing the mini games, the game development approach by Hendrick [17] must be followed, which is a process that includes the prototype, pre-production, production, beta, and live. The prototype involves a process of translating the concepts into low-fidelity and high-fidelity designs. Pre-production involves the documentation of the game design. Production is the game development process, whereby the game assets, design, and code are constructed into a fully functional game. In beta, the game is tested to obtain feedback from the users. Once tested, the game is ready to go live. In this study, the process of prototyping was conducted in the user phase (stage 2) of the RAD methodology. The mini games planned for this study lay in the game production, beta, and live processes, which were the processes conducted in the construction phase (stage 3) of the RAD methodology. In the selection of the game elements and mechanics of the diabetes gamified application in this paper, two considerations were made.

First, the design is based on self-management elements in the gamification for the chronic illness framework in [13] and application of fun elements in motivating a person to sustain their engagement with a health-based gamified application [4,10,13]. With this in mind, the implemented game elements were a logbook (record-based), data visualization (graphs), and alerts. A logbook is any recorded data that relates to given features, such as data concerning medication, appointments, or tasks. For each type of data, the rate of completion is visualized in the form of percentages, using a circle graph on the user's dashboard. Alert messages pop up to remind the user when any of the data is reached or if the given due date has passed. Meanwhile, the selected fun elements are missions, the progression bar, avatar, and badges, as well as the challenges in the mini games. The element of missions in the gamified application allows users to set targets to improve their health condition. The achievement of the missions is visualized through the progression bar. Users will be intrigued to see their progress over time. When any mission is achieved through completing several tasks, a badge is awarded. This badge shows the specific achievement of the users, after which a different user status (novice, intermediate, advanced) is displayed on the user's account. This situation is anticipated to influence the users' engagement with and behavior toward better health self-management. The simulation model is illustrated in Figure 2. The simulation is using machination diagram.

As shown in the simulation, the sources are the data log from the users, in which the data are pooled according to its purpose and indicated by the progress mode. In the simulation, ten data pools were set to be achieved. Once completed, the data are pushed automatically (*) to another pool to indicate the data have been visualized on the application.

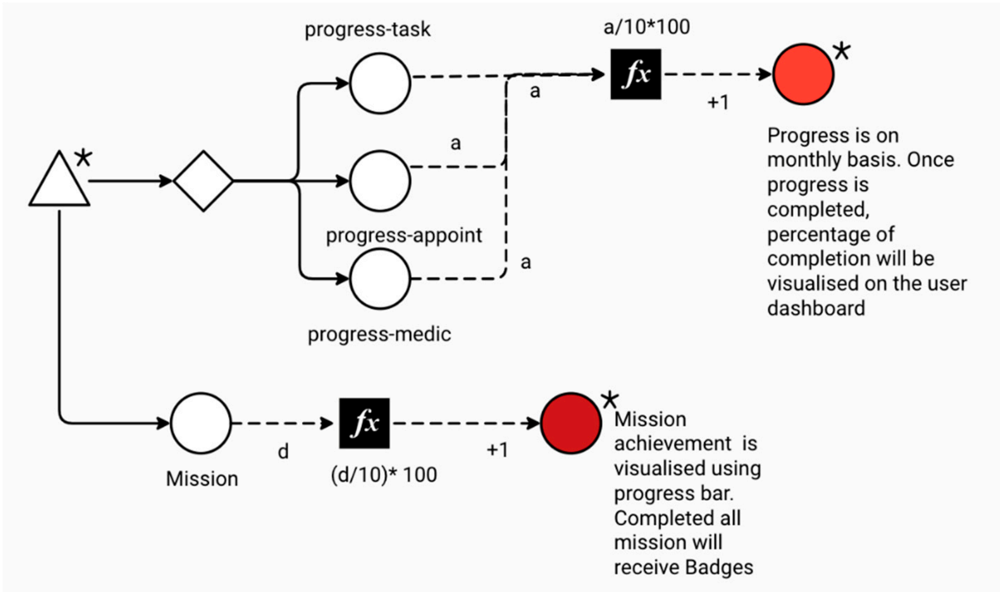


Figure 2. Model of the diabetes gamified application.

Second, the gamified application should follow a particular design pattern. In the literature, there are few available guidelines or frameworks that researchers or developers can use to assess the creation of the gamification design. For example, there is the Mechanic, Dynamics and Aesthetics (MDA) framework [18], Octalysis gamification framework [19], game design guideline [20], and the software engineering of gamification [21]. Each of the frameworks provides a different focus of how a researcher should develop a certain gamified application. However, each of them has a set of rules for good practices in gamification development and implementation. Among them, this study follows the game design guideline by Gallego-Durán [20]. The guideline was chosen because it helps the researcher design the gamified application design by analyzing the strength and weaknesses of the application according to the given characteristic. The guideline has ten characteristics of game-design-based gamification. The rubric of each characteristic is rated between point 0 (low), 1 (medium), and 2 (high). With that in mind, the gamified application yields the following scores:

- (2) Open decision space. Users are in total control of the action taken in the gamified application (continuous space).
- (1) Challenge. The mini games in the gamified application are composed of a series of levels with increased difficulty to challenge the user.
- (2) Learning by trial and error. The mini games are instilled with features that enable users to keep on trying to gain knowledge related to their condition by playing the games. The users can play the games, complete the games regardless of the lost points, and live in the game.
- (2) Progress assessment. The gamified application assesses the user's self-management activities' progress through graph visualization on the user's dashboard. Users who are progressing well and having good achievement will receive a badge.
- (1) Feedback. Users receive feedback from the gamified application in the form of messages and reminders for incomplete tasks.

- (1) Randomness. Some of the features are predicted. However, there will be a surprise movement in one of the mini games in which enemies will come out, and users need to avoid them.
- (1) Discovery. A completed mission will unlock a new badge, new avatar selection, and new mission (health task) to accomplish.
- (1) Emotional entailment. The mini games have a simple story and related character to target user emotion in learning about their condition.
- (1) Playfulness enabled. Playing with the mini games may invoke playfulness with limited room for playing outside the rules set in the system.
- (2) Automation. Even though users need to feed their data manually into the application, the progression, mission, badge, and achievement are automated.

For that, the gamified application gets a score of 14 points in total. The points show that the gamification design can plausibly be considered as accepted, as each of the characteristics is available in the application. However, the gamified application can still be added with more features in the future.

3.4. The Diabetes Gamified Application

The gamified application was designed by the developers (the authors) following the requirements collected in phases 1 and 2. The application interfaces were designed to be user-friendly. The application emphasized certain gamification features that were specifically designed for the users to take advantage of.

In the gamified diabetes application, several functions enable a person to manage their condition. The application requires a person to be registered. Once registered, they need to input and set the necessary information, such as their medication, appointments, tasks related to health targets, and other related treatment. Personal information and health-related data were also needed, for example, emergency contact details, physician details, allergies, and other co-morbid medical conditions. The application also implemented the concept of a personal dashboard, which was designed with the element of progression. This element shows the percentages completed monthly for each component. Visually displaying individual progress at a particular stage makes patients aware of their health status, particularly how well they are coping with their blood sugar control and current existing condition.

In the personal information feature, an element of badges and missions is included. A person receives a badge when he/she has completed or reached 100% on a particular component of the application. Meanwhile, the mission is another game element through which a person can track their health goals. This element of missions is also associated with the element of badges. For example, one individual health mission is to maintain their HbA1c reading at an average level in three consecutive months. From the recorded results, the application rewards the individual with a badge if he/she manages to achieve their mission. Another game element to be implemented in future designs is the element of points, which are received and collected from playing mini games. By playing a series of such games, a person can learn about their condition and obtain points, which can later be used to redeem rewards and items to customize their avatar. Figure 3 illustrates all the functions of the gamified application.

Based on the illustrated functions in Figure 3, the gamified application has three main sections: the user profile, self-management functions, and mini games. Users can manage their basic information via their user profile and add an emergency contact number and medical information (health condition) (refer to Figure 4). Self-management functions are presented through the dashboard (refer to Figure 5a). Users must manage their medication, appointments, and tasks related to their condition (refer to Figure 5b–d). Following the user design phase, three mini games will be installed, consisting of a memory game, an action game, and a role-playing game. The memory game involves memorizing matching pictures about food intake, the essential tools for diabetes, and healthy activity (refer to Figure 6a). Meanwhile, in the action game, users play an adventure activity in a given environment in which they have to collect essential items for a person with diabetes (refer to Figure 6b). For the role-playing game, a rogue-like game will be installed.

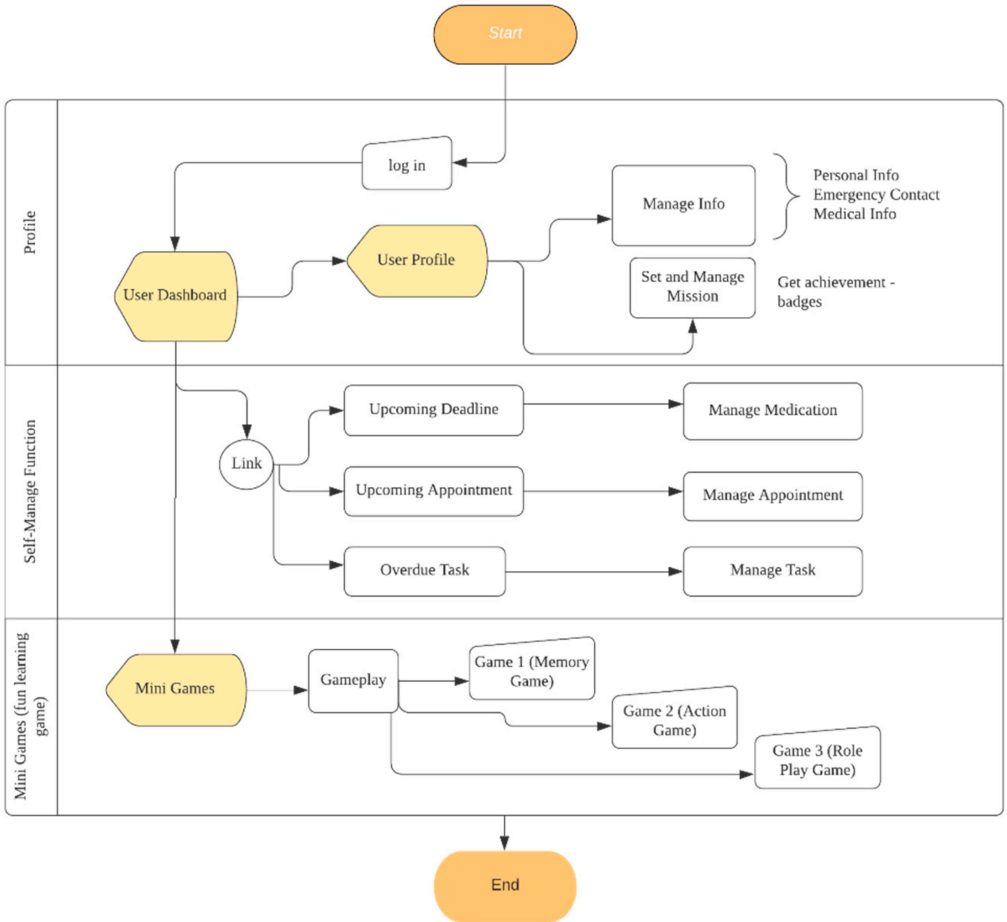


Figure 3. The functions flow in the gamified application.

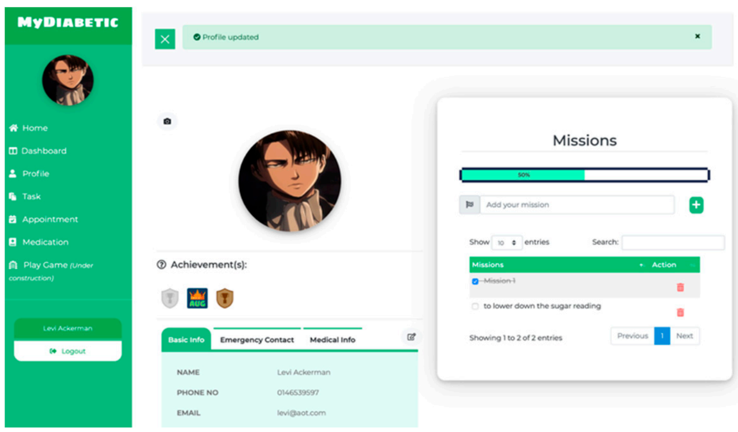
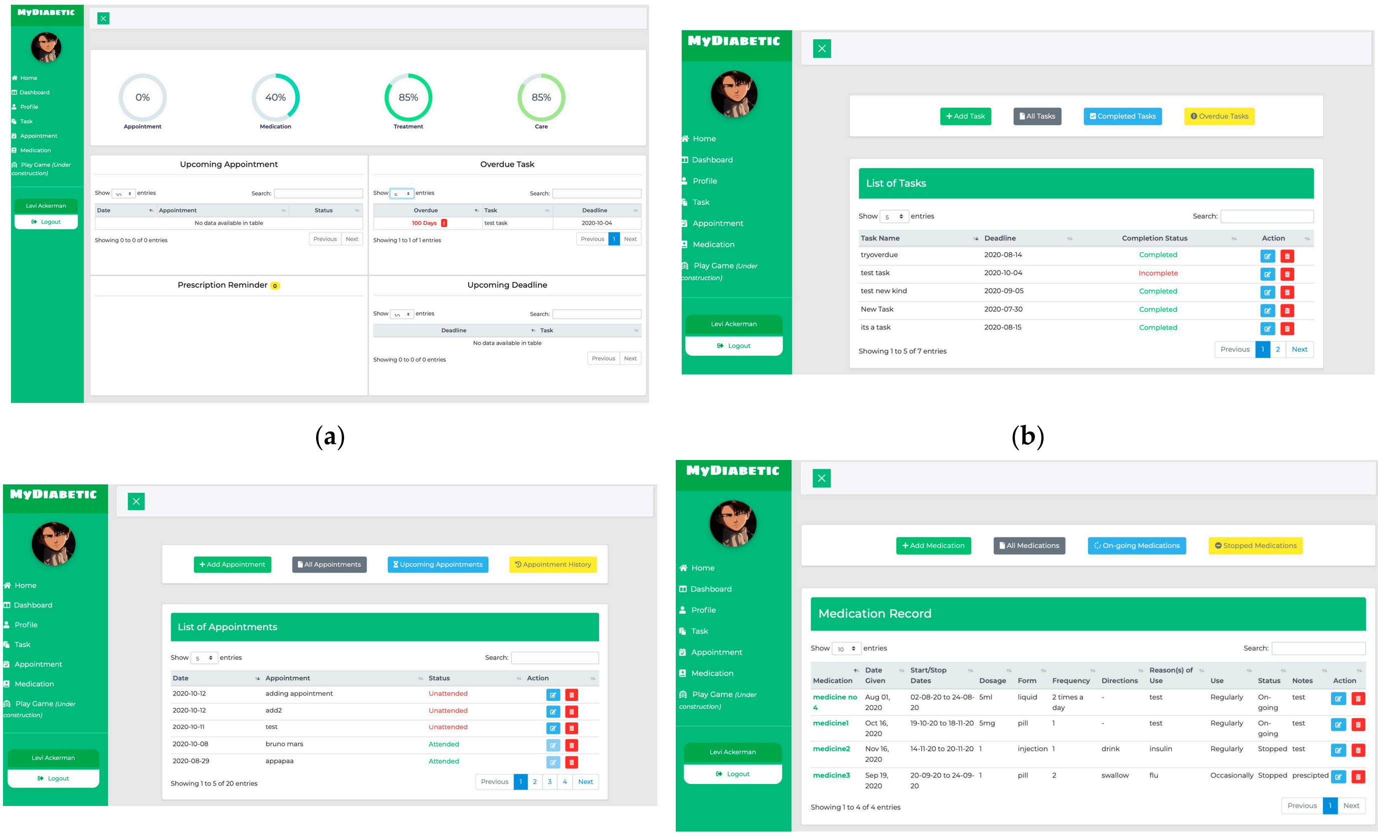


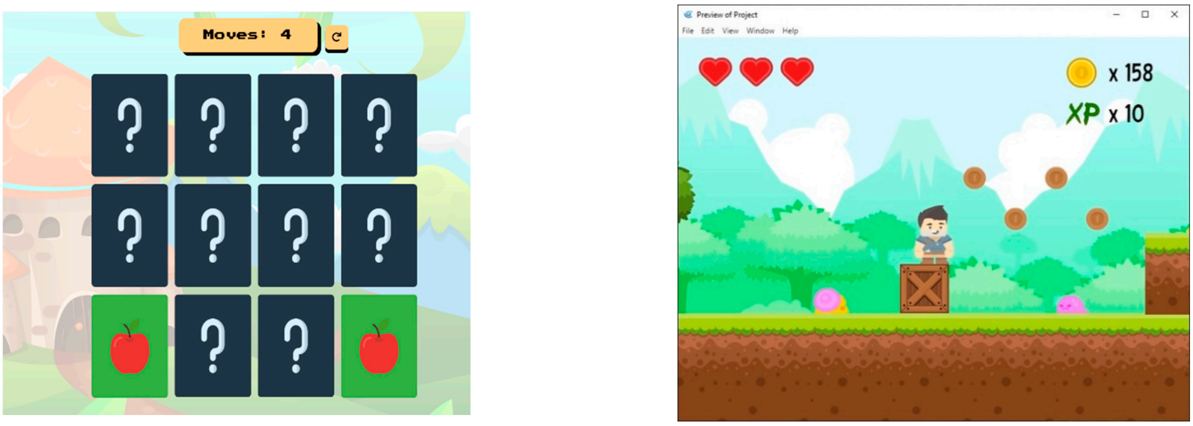
Figure 4. Gamified application—user profile, badge, and mission.



(**a**) (**b**)

(**c**) (**d**)

Figure 5. (**a**) Gamified application—Dashboard and progression; (**b**) Gamified application—Manage task; (**c**) Gamified application—Manage appointment; (**d**) Gamified application—Manage medication record.



(**a**) (**b**)

Figure 6. (**a**) Mini Games—Memory games; (**b**) Mini Games—adventure activity.

3.5. Software Testing Method

In this study, white box testing was conducted for each function in the gamified application. The testing begins with unit testing, which was followed by integration testing. Following that, once each module has been completely developed, the developer generates automated PHP testing. By generating the test, developers can ensure all units are programmed accordingly, and, more importantly, no errors have occurred in the application. The program codes can be identified as practical during the testing, thus minimizing the usage of computer memory resources during the operation (run time).

3.6. Empirical Research Method

Apart from the software automated test, preliminary user testing was also conducted to ensure the programs ran as designed and planned, and all transactions were successfully made without error. This testing was deemed necessary before the researcher could conduct acceptance testing with the potential users (diabetics). In this testing context, the errors were identified from users' misconceptions in determining the system flows. Feedback was also collected regarding the application interface and the way the system worked. For this purpose, the researcher utilized the established Software Usability Scale [22] to determine user perspectives from their use of the application. All the testing processes are illustrated in Figure 7.

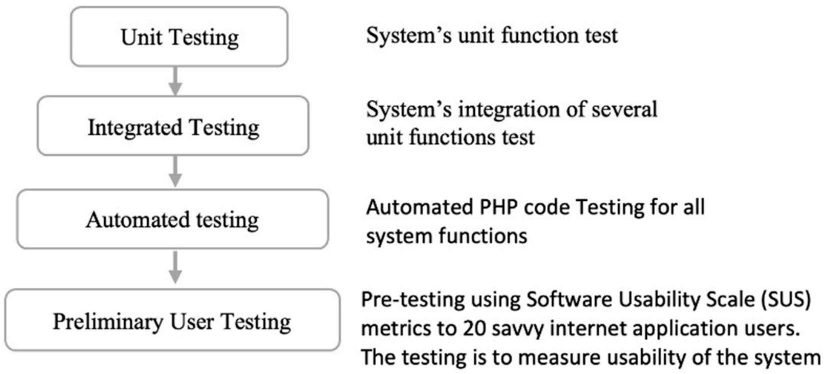


Figure 7. The process of the conducted testing.

Participants and Research Design

The study recruited 20 individuals for the preliminary user testing. These were randomly selected based on their level of familiarity with technology. They had to be familiar with online applications and have a higher internet usage in their day-to-day activities. This number of participants was considered plausible to enable the identification of a reasonable proportion of problems in heuristics usability [23]. Participation was voluntary, and no compensation was given for involvement. The participants were of mixed backgrounds and included persons with and without diabetes.

The testing was designed to be conducted by the users themselves. A call for participation was made via social media and the project website. Interested participants were randomly selected and formally emailed to gain their consent and provide them with participation details. Following the first email, a second email was sent to the participants giving detailed instructions about the testing. The instructions included the step-by-step process for conducting the test and the documentation needed for the testing. The testing was undertaken individually using online resources, and the testers had to refer to the given test cases and complete the testing within the allotted time.

4. Result and Discussion

Twenty individuals participated in the testing. The demographics of the participants are summarized in Table 1. Among the 20 participants, 16 were female and four were male. Their age distribution was between 30 and 40. Five of them had diabetes and 15 did not. However, their diabetes condition was controllable and not severe. These participants were also categorized as being familiar with technology and spent more than three hours per day doing online activities.

Table 1. Participant demographics.

Demographic	No
Gender	
Female	16
Male	4
Age	
30–35	12
35–40	8
Health Condition	
With Diabetes	5
Without Diabetes	15
Tech-savvy hours of daily online interaction	
3–5	5
6–9	12
10 and Above	3

The results of the testing are presented according to the testing activities conducted. There are two parts, the automated system testing and the preliminary user testing. These results suggest the automated unit testing shows no significant errors. The application performance based on the server-side evaluation can be credibly interpreted as successful and suitable for the application environment. With ten simultaneous usages, only 1% of the server memory was utilized (out of 512 MB server memory) with an average response time of 0.335 per second. Based on the results, the application performance was manageable. Users could use the application widely with minimum delay, subject to their network and server performance. Table 2 shows the results of the application server-side performance.

Table 2. Application's server-side performance.

Time (Min)	Load (# Users)	% Memory Utilization	Response Time (Secs)
1	10	1	0.335

The system testing was conducted with 20 participants, and according to the test cases, all functions worked accordingly. The participants were able to follow the system's flow correctly. Thus, no system errors were found during the testing. Apart from conducting the test, these 20 participants also provided additional responses that reflected their opinions of the application. The responses were based on the given questionnaire adopted from the Software Usability Scale (SUS). The questionnaire used a Likert scale of 1 (Strongly Disagree) to 5 (Strongly Agree). There were ten questions, and the results of the mean and standard deviation (SD) of each question are shown in Table 3.

Table 3. Mean and SD of users' responses.

No.	Questions	Mean	SD
1.	I think that I would like to use this system frequently	4.50	0.69
2.	I found the system unnecessarily complex	2.15	0.37
3.	I thought the system was easy to use	4.90	0.31
4.	I think that I would need the support of a technical person to be able to use this system	1.35	0.49
5.	I found the various functions in this system were well integrated	4.05	0.22
6.	I thought there was too much inconsistency in this system	1.20	0.41
7.	I would imagine that most people would learn to use this system very quickly	4.00	0.46
8.	I found the system very awkward to use	1.65	0.75
9.	I felt very confident using the system	4.80	0.41
10.	I needed to learn a lot of things before I could get going with this system	2.15	0.37

The perceived usability of the gamified application was found to be highly reliable (10 items, α = 0.98). Based on the results of the responses, as shown in Table 3, the positive questions (Q1, Q3, Q5, Q7, Q9) received a mean value of 4.0 and above. Furthermore, the negative questions (Q2, Q4, Q6, Q8, Q10) received a mean value of 2.5 and below. Additionally, based on the SUS scores interpretation, the total scores for each participant were multiplied by 2.5 to convert the scores into a 0–100 range. Scores above 68 were considered above average, indicating acceptable usability. Users rated the gamified application as very positive, with an average score of 76.87; the obtained score was above the average SUS score. The obtained SUS score recorded a median score of 76.25; the minimum score was 70; and the maximum score was 85. Figure 8 shows the boxplot of the SUS scores for all users.

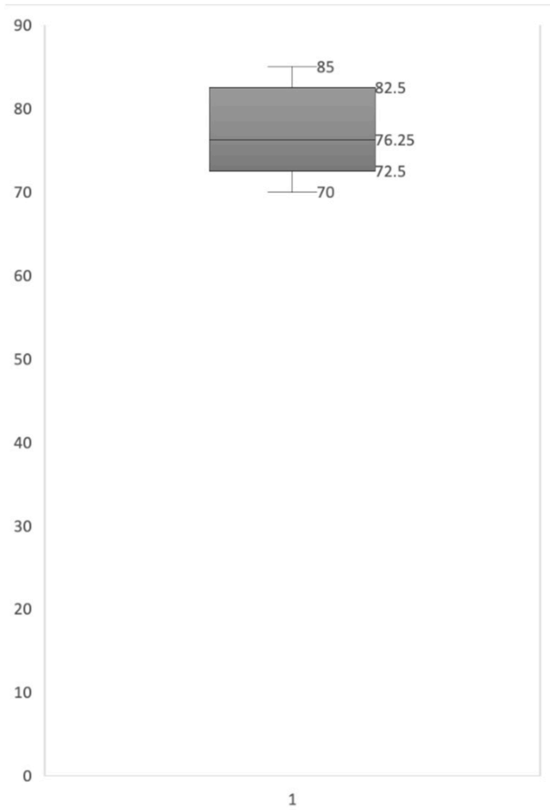


Figure 8. Software Usability Scale (SUS) overall participants scores.

The results in Table 3 and Figure 8 show that all participants agreed with the functions provided in the application, that the application was not complicated, and that learning to use the application was easy without the need of a technical support person. Thus, the users gained a reasonable level of confidence in using the gamified application. The users understood the process and were willing to use it further. Therefore, we assumed that the application was ready for actual user acceptance testing (tested by a diabetes patient). Although a direct comparison with the previous study in [10] may not be applicable, due to the different focus of the diabetes self-management implementation, the findings show that the gamified application implemented in this study is systematic, with consistent but not complex features. A comparison with the outcome of previous studies in [9,24] reveals a similar pattern in the need for a simple application whose functions are not overly difficult and whose design is relevant in its gamification elements and techniques. Hence, this finding has established the underpinning concepts of applying gamification for health self-management.

Nevertheless, certain limitations of this study were noted. First, the conducted testing was a self-regulated activity, which was conducted online due to the pandemic situation and movement restriction order. This resulted in a limited level of observation of user behavior during the activity. Moreover, the testing activity was conducted over a short period. Thus, future work should consider longer experimental periods and evaluate a person's improvement in their health condition when the application is used. Second, one mini-game (the role-play) still needs further improvement, as it received several comments during the testing. Most comments concerned the patient's avatar (role-play character). It was suggested that the avatar should reflect the level of a patient's condition in the gameplay and gradually change as the condition of the patient improves. This suggestion is in line with the avatar implementation in a previous study [5] in which the avatar changes further explain the positive effect on the user's engagement in the gameplay. Meanwhile, other comments were directed toward the interface designs, which have been altered by the developers. Nevertheless, any comments and suggestions on the current functionalities could inform further improvement.

5. Conclusions and Future Work

The application of gamification for diabetes mellitus is gradually receiving attention as a tool and part of an individual's daily life activities. Providing an application that could help individuals learn more about their health condition indirectly teaches and encourages them to self-care and self-manage. Providing such an application also allows individuals with diabetes to adapt to their daily routine by themselves. However, individuals with little or no familiarity with using the Internet and technology find such applications challenging to use. This scenario could occur with older adults who are more accustomed to manual book records, nurse call reminders, and the physical diabetes awareness program. Nevertheless, personalized healthcare monitoring, such as the developed gamified application presented in this study, has been created for anyone who requires assistive tools in self-managing their diabetes condition.

This research reports the development and testing work related to the completion of a gamified application. The work was grounded in the RAD methodology, with the requirement and design phases having been completed. The developed application underwent preliminary user testing to assess the application's usability with the Software Usability Scale (SUS), and the results were encouraging. The results from the usability study show that the gamified application is generally easy and practical to use whether the individual is living with or without diabetes. The users also indicated that they would like to use the application frequently. However, currently, there is no proof that the system could improve a person's health condition. This should be taken into consideration in future studies.

Therefore, in future work, the researchers will conduct acceptance testing and assess the application's effectiveness for prospective users. A longitudinal study inspecting how a person could benefit from the gamified application, as well as how the application could affect the condition of a person's diabetes, will be further researched. The longitudinal study is considered necessary to measure any medical impact on a person when using a particular system application. The system effectiveness requires time and a monitoring method, such as a diary, to acquire comprehensive results. In the interim, suggestions for application improvements will be put into action. Meanwhile, other application improvements, such as developing a mobile apps version and adding more mini games, will be considered for future work.

Generally, the developed gamified application in this study can be considered a possible future solution for modern healthcare services. The application is an open platform, which currently involves diabetes as the subject of interest. Applying other health conditions as subjects of a gamified application can also be further explored.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/computers10040050/s1.

Author Contributions: Conceptualization, N.M.T. and A.Y.; methodology, A.Y.; formal analysis, F.A.; writing—original draft preparation, N.M.T.; writing—review and editing, A.Y. and F.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research is funded by the Universiti Malaysia Sabah, grant number SLB0201-2019 and the APC is funded by the Universiti Malaysia Sabah.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Medical Research & Ethics Committee of Ministry of Health Malaysia (NMRR-19-1732-49011 and 7 October 2019).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data are contained within the article and can be found in the Supplementary Materials.

Acknowledgments: The authors would like to thank Universiti Malaysia Sabah for this research opportunity and the financial support during the completion of this research. In addition, the authors would like to thank the research assistant who administered and coordinated the testing accordingly.

Conflicts of Interest: The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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Article

Developing Emotional Intelligence with a Game: The League of Emotions Learners Approach

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Abstract: Being able to understand, express, and communicate emotions is widely recognized as a fundamental competence. For the younger generation entering the professional market, this is particularly relevant as, in this context, emotions are managed and communicated in ways (and channels) that are different from what they are used to and that can easily lead to misunderstandings. Therefore, it is important to analyze how young people deal with, understand, and interpret emotions, particularly in the context of a professional career where the ability to dialogue with different people and how to get around problems in a healthy and resilient way is essential. This analysis will allow one to design and create tools that allow the younger generation to improve their emotional intelligence and competence. This article introduces the League of Emotions Learners (LoEL) project, an innovative initiative that, through a game app, develops the emotional competence and intelligence of young people. The article then presents the results obtained in the initial validation that led to the positive understanding of its impact.

Keywords: emotions; emotional intelligence; serious games; apps

Citation: Santos, J.; Jesmin, T.; Martis, A.; Maunder, M.; Cruz, S.; Novo, C.; Schiff, H.; Bessa, P.; Costa, R.; Carvalho, C.V.d. Developing Emotional Intelligence with a Game: The League of Emotions Learners Approach. *Computers* **2021**, *10*, 97. https://doi.org/10.3390/computers10080097

Academic Editor: Paolo Bellavista

Received: 19 July 2021
Accepted: 2 August 2021
Published: 10 August 2021

1. Introduction

Emotions are universal, ubiquitous, and have a large impact in all the aspects of our lives. Emotions shape our relationships and define how we interact with family members, friends, coworkers, and other people that we meet during our lives. Experiencing an emotion allows us to evaluate and perceive a concrete situation following a pre-existing set of cognitions, attitudes, and beliefs about the world.

Emotional competence is a basic ability that characterizes emotionally intelligent individuals. Having emotional competence implies being able to establish healthier relationships and to deal with adversities. Individuals without emotional intelligence do not have the ability to master their emotions, and this means that they might be unable to communicate properly and, therefore, be led to act inappropriately due to a misunderstanding of situations. Hence, emotional intelligence is a significant competence for professional success as it depends on how emotions are dealt with in terms of the ability to influence, communicate, collaborate, solve conflicts, and work in a team.

To some extent, it is possible to improve one's emotional competence or, at least, some of the inherent aspects such as emotional self-consciousness, emotional self-control, self-motivation, empathy, and social skills. The League of Emotions Learners (LoEL) project promotes this development and provides a bridge to overcome the emotional intelligence gap between the younger professional generation and the organizational context in companies. It mainly seeks to empower the youth so that they can express and communicate emotions, are aware of the cultural factors behind the expression of emotions, and can acknowledge the importance of the media channels on the shaping of an emotional message. By using the project outcomes, young people are expected to be able to identify, understand, manage, and communicate their own emotions and other people's emotions.

1.1. Emotional Intelligence

Emotions are biologically based states translated into thoughts, feelings, and behavioral responses that are brought on by neurophysiological changes [1,2]. Emotions work for us in the sense that they guide our behavior and our thinking process, particularly when a rapid response is needed to sudden (sometimes, critical) situations. They also help to relate to other people, manage expectations, and understand and respond to life challenges. As mentioned before, emotions are normally triggered from an occurrence and their perception, which can be conscious or unconscious. The occurrence can be external or internal, current, past, or future, real or imaginary. There is an innate mechanism that values the stimuli that reach our senses and generates the corresponding emotions. If the happening is assessed as positive, it is perceived as progress toward wellbeing and generates positive emotions. On the contrary, if the happening is assessed as negative, it generates negative emotions.

Individuals react differently to similar situations as emotions change according to how everyone feels and sees the world and how they interpret the actions of others. We evaluate what is happening in a way that is consistent with the emotions we are feeling, thus justifying and maintaining the emotions. Moreover, emotions produce changes in the part of our brain that mobilizes us to deal with what has set off the emotion. Emotions also cause changes in our automatic nervous system (which regulates our heart rate, breathing, sweating, etc.), preparing us for different actions. Facial expressions, as part of this mechanism, do not just communicate emotions, they also increase those that a person is feeling and send signals to the body to issue a consistent response.

The identification of emotions and, particularly, the basic (or most important) ones has been the subject of a wide and extensive debate in the psychological community. In his revised proposal, Ekman proposed what is nowadays the most used model (even if Eckman himself has somehow moved on from this approach) that includes six basic emotions: sadness, disgust, happiness, fear, surprise, and anger [3]. The other emotions (more than 50 already identified) such as shame, revenge, and hope are linked to these six basic emotions. Ekman's view included the notion that emotions are discrete, measurable, and physiologically distinct as the subjective and physiological emotional experiences matched the distinct facial expressions.

Emotional intelligence is the ability to distinguish and manage emotions and to use this knowledge to manage one's thoughts and actions. It is "the ability of a person to monitor one's own and other people's emotions, to discriminate between different emotions, to label them appropriately, and to use emotional information to guide thinking and behavior" [4]. It is also the ability to recognize other people's feelings and one's own and to be able to motivate and handle properly the relations that we have with other people and with ourselves. Goleman proposed that an emotionally intelligent person should be able to differentiate between distinct emotions and to devise an accurate and effective plan of action to respond to different situations and scenarios [5]. He further detailed that an emotionally intelligent person should be an effective handler of others' emotions by manipulating body language and conversations to manage and regulate others' emotions in a favorable direction to the goals of the parties.

Emotional competence therefore is defined as a set of knowledge, abilities, and attitudes that allows one to be aware, understand, express, and manage appropriately an emotional phenomenon. Schutte, Malouff, and Thorsteinsson argued that a person is competent in the perception of emotions if they can recognize emotions from the voice and facial cues of others, as well as be aware of one's emotional state and reactions [6]. This competence increases the personal and social wellbeing through emotional conscience, emotional regulation, emotional autonomy, social competences, and wellbeing and social abilities.

Emotional conscience is the ability to be aware of one's own emotions, to be able to identify and classify emotions, to use emotional vocabulary and expressions, to understand other people's emotions, and to be aware of the interaction between emotion, cognition, and behavior.

Emotional regulation allows one to understand that the internal emotional status might be different from the external expression, to regulate one's emotional expression, to face challenges and conflict situations and, finally, to be aware and capable of generating positive emotions.

Emotional autonomy provides a positive image about oneself (self-esteem), allows one to be involved in diverse activities of daily life, to be capable of making and maintaining social relationships, to take responsibility of one's actions, to have a positive attitude, and to face adverse situations.

Social competence allows one to manage basic social skills, to respect others, to practice receptive communication, and to take responsibility for one's actions.

Wellbeing and social abilities involve the ability to set-up goals, to search for help and resources, to identify the need for help, to develop an attitude of awareness of the rights and duties as a citizen, and to create optimal life experiences.

Emotional competence is especially important for teenagers and youth, in general. During this stage of life, young people will move away from their families and will be closer to their peers and to the labor market. This can be a difficult time especially if the young person cannot understand their own or other's emotions. Young people who develop their emotional intelligence early become more empowered, are more aware and assertive, and are able to solve problems more easily, and they cope better with tough/stressful situations at work.

1.2. Emotional Intelligence in the Professional Context

Emotions are naturally present in the professional world. Knowing how to recognize one's emotions and to understand how they affect oneself and others can contribute to better manage the adversities of life and to deal with unforeseen events that happen in daily professional life. Being emotionally intelligent allows an employee to perceive, understand, utilize, and manage emotions effectively in a professional context [7–10].

Organizations consider emotional intelligence as an important skill, due to its significant impact on the various aspects of the business community, especially employee development, performance, and productivity [11]. The Emotional Quotient (EQ) has been included as a factor for hiring employees, together with the Intelligence Quotient (IQ), academic credentials, and work experience [12]. Emotional intelligence has a direct association with employee performance and professional success [10,13–15]. Having emotional control is essential to maintain a positive and adequate professional posture, and knowing how to deal with emotions and different personality types in the professional environment is vital to a successful career. It can also improve the emotional wellbeing of all colleagues in the professional environment. Additionally, it improves the quality of the services that the organization itself provides as it improves the relationship with clients, favors employee's loyalty, prevents conflicts, and gives positive solutions to conflicts.

2. League of Emotions Learners

The League of Emotions Learners (LoEL) project aims to empower young people to develop their emotional competence, to be able to identify and express self-emotions, and to establish successful online and offline communication. The project was particularly concerned with professional environments and, as such, had five main objectives:

- To develop empowering training resources that allow young people to identify the origin and nature of the emotions.

- To facilitate a diverse set of activities that combines real digital communication methods and channels with work and personal environments.
- To disseminate linguistic expressions that express basic emotions in different cultural backgrounds.
- To teach appropriate verbal and gestured indicators to send effective messages in negotiation and conflict situations.
- To provide enterprises and organizations that work with young people with a motivating training approach.

The project targeted young people and youth trainers that could benefit from the use of the results in their personal and professional lives, by becoming more aware of their emotional intelligence, being able to recognize the benefits of managing one's emotions, and knowing how to express emotions and how to communicate through videos, pictures, and audio. Moreover, they can benefit by knowing how to discover how new technologies and their own channels and signs can shape communication and can be used to express emotions.

The LoEL approach brought together key aspects that, normally, are not interrelated in a training process: the importance of language in the identification and expression of emotions and the recreation of professional scenarios though learning by doing and gamifying strategies adapted to the business world.

2.1. The Guide for Youth Worker

The first result of the project was a set of ideas, resources, and examples addressed to the youth trainers to support them in their work with the young collective. These materials were created with the objective of providing these professionals with game-based and nonformal learning methodologies focused on emotions' identification and management. The methods and contents are not only transferrable from the online to the offline scope, but also from the informal and nonformal to formal education, so youth trainers and educators can produce innovative programs. This result was called the Guide for Youth Workers and the offered practical tools allow youth trainers to facilitate learning environments where emotional competence development is the core topic. The guide also explains the LoEL pedagogical concept and approach and explains how to use and replicate it.

2.2. The LoEL App

Communication has evolved and changed, and nowadays, digital audiovisual communication has gained extreme relevance. Young people are normally digital natives, that is, they grew up in close contact with computers, the internet, video game consoles, mobile phones, social media, etc. According to different studies, children now receive their first phone at the age of 10 and start interacting in social networks at the age of 14. Additionally, they frequently play with digital devices such as consoles and smartphones. This means they interact with digital audiovisual material from childhood, and this is their preferred way to connect to the world and to express emotions. Therefore, it is important to be aware that, for some people, it is much easier to express emotions using other channels rather than talking. Accordingly, the League of Emotions Learners tool (Figure 1) was conceived as an interactive mobile app (currently available from the Google Play Store—https://play.google.com/store/apps/details?id=com.virtualcampus.loel and Apple AppStore—https://apps.apple.com/app/id1501537657, accessed on 29 July 2021) designed to empower young people to be able to identify, manage, communicate, and understand their own and other people's emotions.

Figure 1. LoEL App introduction.

The LoEL app implements innovative gamified educational practices that include specific activities based on the digital habits of young people. This combination of digital content in the form of a Serious Game available through a mobile platform is highly effective for the addressed target group, measured by their ability to translate the acquired competence in real tasks [16]. Serious Games, defined as games designed with a serious purpose [17], are immersive and motivating due to their embedded enjoyment and emotional gratification [18], and they build training environments that allow the acquisition of knowledge, experience, and professional skills through the simulation of different situations and contexts [19,20], which can be well adjusted to the LoEL target group [21]. Therefore, the app design followed a set of requirements:

- Designed as a digital mobile tool as the best option considering the target group (young people). The visual design of the app also took into consideration this target group, as it can be seen in Figure 2.
- Designed to develop emotional intelligence skills and to contribute to increased theoretical knowledge and, through the types of games and scenarios contained, to enhance the development of practical interaction skills in real professional contexts.
- Designed to increase sensitivity toward intercultural communication in professional contexts and interpersonal interaction.
- Designed to increase the ability to establish a healthy relationship between employer and employees, an extremely important factor for young people who are recently in or will enter shortly the labor market.
- Designed to help identify and express self-emotions and to establish successful communication with others both in online and offline forms.
- Designed to increase the awareness of the limits and potential of digital communication.

The LoEL App integrates resources and activities that explore emotional intelligence in different ways:

- EMOTIONS BOX is a multilingual dictionary of emotions, with the definitions and examples for the 50 most easily identifiable emotions (divided in basic and secondary emotions).
- EXPRESS YOURSELF provides different games to test and develop the players' ability to express themself. Examples of the included games are:
    - Identifying emotions based on a definition.
    - Identifying emotions in images (Figure 3).
    - Identifying images that represent an emotion.
    - Asking the user to show a specific emotion.
    - Completing a comic story, where users must create the correct dialogue lines for a proposed narrative focused on a specific emotion (Figure 3).
    - Asking the user to identify emoticons based on the name of a movie/song and vice versa (Figure 3).
    - Filling-in the blanks exercises with sentences that use common jargon terms.

- ○ Identifying emotions present in short video clips (Figure 3).
- ○ Identifying emotions present in idiomatic expressions.

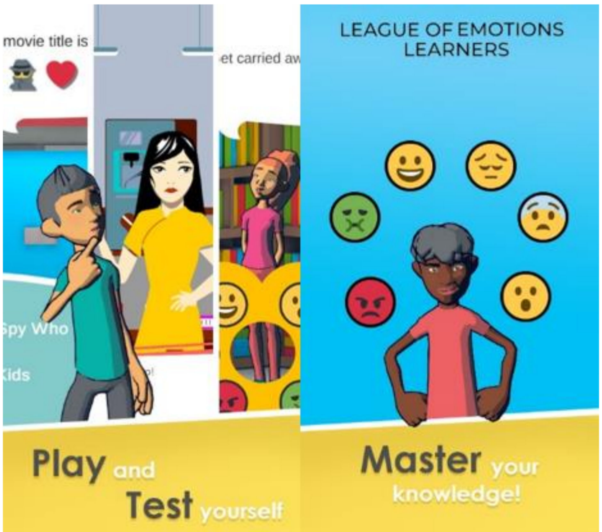


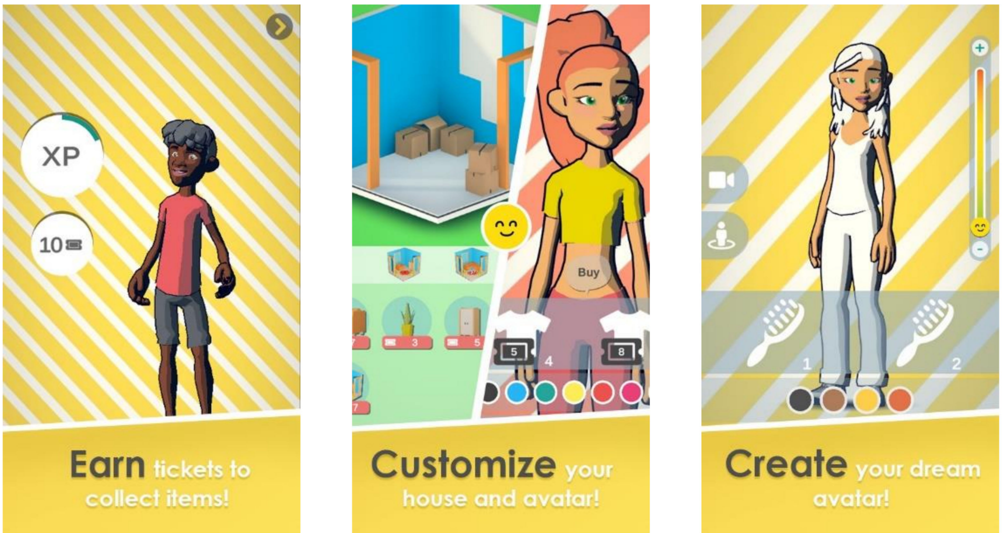
Figure 2. LoEL app visual design.

Figure 3. Different games in the LoEL app.

EMOTIONAL ORGANISATIONS is an activity that puts the player roleplaying and practicing how to manage emotions in professional backgrounds through simulated scenarios (Figure 3). These activities are classified in four areas that are essential for the management of a company's emotional intelligence: ability to control emotions, ability to motivate oneself, recognition of other people's emotions, and control of relations.

The app includes a difficulty progression system that moves the players through different levels of complexity. Currently, there are 4 different levels and, following feedback from the users, the progression, based on experience points, follows a logarithmic approach. That means that users can move quickly from the first level to the second level, need more points to move to the third level and even more points to get to the final level. The difference between levels is related to the addressed emotions (just the basic ones in the first level and then moving to the secondary ones in the other levels) and to the available types of games (more immediate games such as identifying emotions in photos in the first level and more complex games, such as the organizational scenarios, in the last level). Some game aspects such as the number of experience points and tickets received in a game and the available customizable items also depend on the level.

To allow a better identification between the user and the game, the players can create their own avatar and customize it with a set of accessories or elements (skins, objects, pets . . .). While playing the game, the players collect tickets that allow them to further customize their avatar and home (Figure 4).



(**a**) (**b**) (**c**)

Figure 4. Customization of the avatar (**a**,**c**) and home (**b**) through the ticket system.

The app is available in 5 different languages, which of course implies a large degree of localization due to the cultural aspects related to language, signs, and emotions.

3. Results

The testing of the app followed a standard approach with alpha, beta, and piloting (gamma) stages. Alpha testing was carried out by internal staff of the involved organizations; beta testing was conducted with youth and youth workers in the involved partner countries: Spain, Portugal, Italy, UK, and Estonia; finally, piloting was conducted with a large number of users from all over Europe.

Alpha testing provided mostly a qualitative set of comments that allowed one to improve the ticketing and difficulty/level system, the graphical design of the app, and the design of the games. An important aspect was the feedback that should be provided to the user to render the development of the emotional competences more effective.

Beta testing was conducted with 110 participants, external to the LoEL consortium, mainly youth trainers (59.6%) and students (10.1%), spread evenly between the involved countries. The testing stage provided quantitative and qualitative feedback concerning the usability, game experience, and effectiveness in emotional competence development.

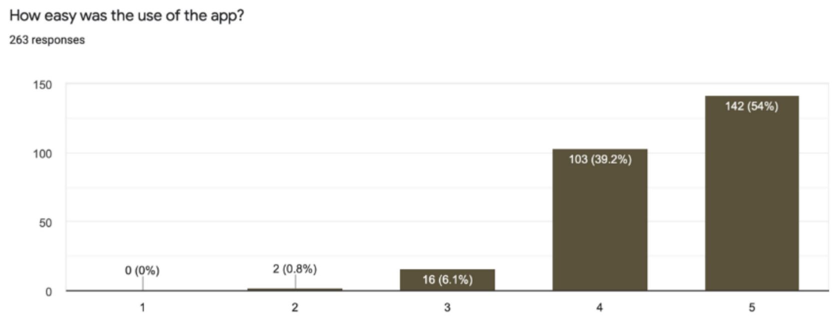
Here, 90% of the testers found the features of the app with ease and only three participants were not able to interact with the app. The interaction features of the app were therefore rated very high ($x = 4.2$) on a 5-point scale. The content was also rated highly ($x = 4.1$) and the transferability of the knowledge to real life was scored 3.7. More than 75% of testers thought that the app promoted knowledge and understanding of emotions; 67% of the testers thought that the app provided relevant information for people who work with youth; 64% of them also thought that the app provided competences for emotion handling; 65% of the users would use the app again.

The comments about the app were quite diverse. They complimented the idea of putting emotional education into a game and the originality of the content and the connectedness to real life. They mentioned the high number of games, the nice interface, and the interactivity of the app. Some liked to earn the coins and refurbish their room. They said that it was easy to use and attractive to young people. The game elements were well implemented, the graphics, sound, and music were catchy and effective, and they loved the use of primary colors and the wide range of options when creating an avatar.

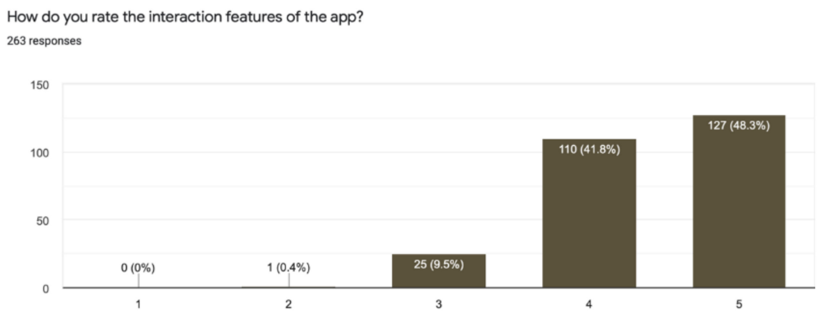
A few participants thought that some games were too hard and that it was difficult to progress in the game, especially in the beginning. One trainer said that: "I like it very much because it actually gives you the opportunity to create a session on it. You can start a discussion on emotions and on how they affect people's reactions. You can organize different activities providing the app to the participants. There are different levels that allow you to improve and try new games" and another teacher said that: "I liked the challenges it gives you to unlock other games and the content such as Jargon Words, for a teacher as me are useful working with my students to learn even more their words". Suggestions for improvements were mostly about user friendliness and the elements of the user interface. In addition, some comics were hard to read because of the font/animation. Some changes to the progress system were also suggested.

The pilot testing was open to the general audience and was meant as having the end users assessing the usability, game experience, and emotional competence development of the app. Although, at the time, the app had more than 2250 users, it was only possible to collect feedback from 263 that answered an online anonymized questionnaire. Users were spread throughout Europe, with the UK (33.5%), Estonia (20.8%), Romania (17.7%), and Portugal (16.5%) as the leading countries. The average age of the inquired was 23.4 years old, where 65.8% (173) of them were female and 33.5% (88) were male, and 2 people did not specify their gender. In addition, 63% of the people had higher education and 21.8% had completed high school; others had more specific educations such as vocational training.

As can be seen in Figure 5, the app was highly rated on usability and interaction (a 5-level Likert scale was used with 5 as the most positive), as can be seen in the next two graphs. In addition, 89.3% of the users also mentioned that it had been easy to find all the features of the app.



(**a**)



(**b**)

Figure 5. Evaluation of the easyness of use (**a**) and interaction (**b**) features of the app.

The contents of the app were also rated very highly, as can be seen in Figure 6. Most people (77.9%) thought that the app promoted knowledge and understanding of emotions and that the information provided by the app was relevant to most people's needs (60.3% of the users). Most people (77.6%) agreed that the app contributed to developing emotional intelligence, although 17% were not so sure about this aspect.

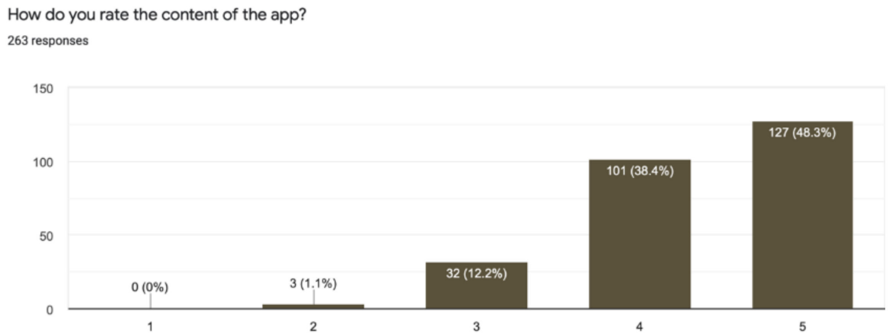


Figure 6. Ratings for the app content.

Most of the respondents mentioned that they would use the LoEL application again, as can be seen in Figure 7.

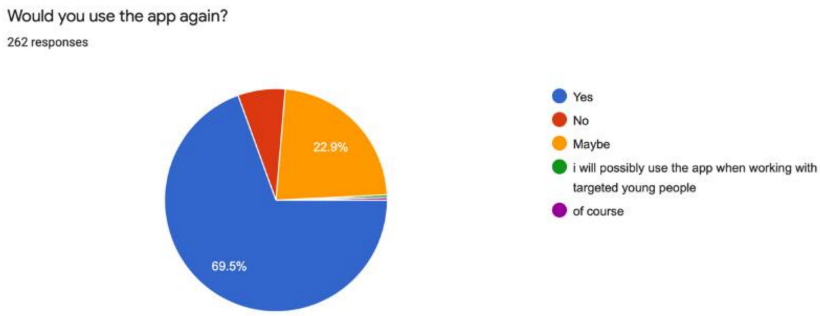


Figure 7. Willingness to use the app again.

Testers were also asked to provide qualitative feedback about the app, which is summarized as follows:

- They were fond of the personalization of the avatar and the originality of the content. The content was considered attractive and fun. It was easy to use, and the design was considered as attractive.
- The app provided seamless learning; it felt just like playing without realizing that you were actually learning. They learned many unknown feelings and words. They also realized that, often, we do not understand the feelings of others. Several of the games were presented as the favorites.
- There were very few negative comments: one user did not like some of the used pictures, another disliked the music. One complained about the little variety in the first level and that it took a lot of effort to move to the following levels.
- Testers also gave recommendations to make the application better: more attractive graphics for teenagers as the design was thought to be more for a younger audience; more games, content, and variety in the games; more customizable options such as a non-binary gender, other clothes, or furniture; a more thorough introduction on what are feelings, emotions, and emoticons; the possibility to connect it to social media; more variety in the music and more agility.

One thorough and helpful comment mentioned that " ... instead of right or wrong answers, let them earn points by using the app more doing more exercises there or something. Encourage them to think that everything they feel is right, instead of no that was wrong. I also think that this app could be more interactive. The idea behind of it is great, though".

4. Conclusions

Emotions provide information about oneself and the others and constitute a feedback system that delivers information that drives behavior and decisions. Emotional intelligence has been acknowledged as a key success factor both in personal and professional life and there is a need to develop the emotional competence of young people so that they are successful in both domains.

The League of Emotions Learners project sought to empower this collective for them to be able to understand, manage, express, and communicate emotions. The LoEL app was created as a tool that young people could relate with that precise objective. Looking at the testing and evaluation results, it is possible to state that the overall outcome of the project was accomplished in a very positive way, and it is also important to note that the positive results were independent (with only minimal differences that may be due to slightly different testing conditions) in relation to gender (4.5 vs. 4.3 average in content rate for male and female participants and 4.5 vs. 4.4 in interaction rate), education level, age (4.36 vs. 4.32 in content rate for younger vs. older students and 4.39 vs. 4.38 in interaction rate), and country (4.1 in Spain vs. 4.6 in Portugal and England in the interaction rate and 4.1 in Spain vs. 4.6 in Italy in the content rate). These results were surely a consequence of the constant and consistent feedback from the end users—young people and youth workers—throughout the project.

Author Contributions: Conceptualization, J.S.; methodology, J.S., T.J., A.M., M.M. and C.V.d.C.; software, P.B., R.C. and C.V.d.C.; validation, T.J. and C.V.d.C.; investigation, J.S., T.J., A.M., M.M., C.N., H.S. and C.V.d.C.; writing—original draft preparation, S.C.; writing—review and editing, C.V.d.C.; project administration, J.S.; funding acquisition, J.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was partly funded by the European Union, through the Erasmus+ programme, KA2 action, under the grant number 2018-1-ES02-KA205-011836.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: All data has been present in main text.

Conflicts of Interest: The authors declare no conflict of interest.

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computers

Article

An Interactive Serious Mobile Game for Supporting the Learning of Programming in JavaScript in the Context of Eco-Friendly City Management

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Received: 13 November 2020; Accepted: 15 December 2020; Published: 17 December 2020

Abstract: In the pedagogical process, a serious game acts as a method of teaching and upbringing, the transfer of accumulated experience and knowledge. In this paper, we describe an interactive serious programming game based on game-based learning for teaching JavaScript programming in an introductory course at university. The game was developed by adopting the gamification pattern-based approach. The game is based on visualizations of different types of algorithms, which are interpreted in the context of city life. The game encourages interactivity and pursues deeper learning of programming concepts. The results of the evaluation of the game using pre-test and post-test knowledge assessment, the Technology Acceptance Model (TAM), and the Technology-Enhanced Training Effectiveness Model (TETEM) are presented.

Keywords: serious game; gamification; game-based learning; programming teaching; sustainability teaching; mobile app

1. Introduction

Ubiquitous learning is an emerging educational paradigm that is based on digital content, mobile devices, smart environments, and wireless communication to provide teaching–learning experiences to learners at anytime, anywhere, and in any way [1]. Ubiquitous learning allows students to break beyond the traditional classroom-based setting of formal education and to interact with different computing devices and digital technologies in a blended way. An important enabler of ubiquitous learning is serious games, i.e., games whose primary purpose transcends pure entertainment [2]. Specifically, educational serious games primarily aim at education rather than entertainment [3]. They have been shown to promote critical thinking and strategic and logical skills in computer-supported learning environments [4].

In pedagogy, serious games are used as an attractive way to transfer experience and knowledge to a learner [5]. The implementation of serious games as a part of teaching curricula leads to the gamification of education and instruction, which is considered to be appealing and engaging among the learners [6,7]. Gamification is designed to make the necessary routine fascinating, whether it is the study of a large amount of information, but at the same time leaving the person in his/her reality, by himself/herself, allowing him/her to improve the skills necessary for this particular subject. The game and game technologies in pedagogical practice depend on the creation of certain conditions for achieving goals, the modeling of a special game reality with its internal laws (role-playing games, business games, organizational activity games, etc.). Games complement traditional forms of education and contribute to the activation of the learning process and the successful implementation of collaboration-based learning [8] in practice. Unlike in traditional teaching resources and digital media, educational games provide a virtual space for learners, in which learners can practice and actively engage in the subject of learning without being subject to the stress typically associated with formal learning [9].

Games have a strong emotional impact on students and can help form many skills and abilities: first of all, communication skills, the ability to work in a group, to make decisions, and to take responsibility for oneself. Serious games combined with other educational technologies increase the effectiveness of programming education. Recent studies claim that learning outcomes and learner engagement are improved when using digital game-based learning versus traditional teaching methods [10]. In contrast to entertainment-only games in general, pedagogy-oriented games have an essential feature—a clearly defined goal of teaching and corresponding pedagogical results that can be substantiated, singled out in an explicit form, and are characterized by an educational and cognitive orientation [11]. The reasons why students love computer games can be summarized as follows:

- computer games represent fantasy and follow a simple principle: win or lose with instant results [12];
- games use aesthetic modeling and recognizable features to grab the learner's attention with visual feedback [13];
- games are an interactive environment and provide complete immersion in it [14];
- games open up different ways to solve problems [15].

The multi-aspectual nature of computer games creates an opportunity to develop creativity, technical skills, and collaborative work experience [16]. Moreover, they have been demonstrated to positively affect students' learning outcomes [17,18].

Several studies claim that students usually prefer playing a serious game over traditional pedagogical methods in several areas of science, technology, engineering, and mathematics (STEM) education (see, e.g., [19] for a comprehensive case study for mathematics). Certain qualities of educational games can help increase student interest: a challenge that encourages the learner to explore a specific topic and bring knowledge and skills to perfection because only in this case can one go to the next level. In particular, programming education for non-STEM students should use enjoyable game-based tools to overcome their anxiety, increase their engagement and motivation [20,21], and support computational thinking [22]. There is no single definition of serious games. The disagreements and discrepancies among definitions of serious games lead educators, tutors, and mentors into confusion when they try to figure out which games should be used for effective teaching. The general point of view is that:

- a learning model is built into such games;
- they have content that the process of playing the game teaches;
- learning assessment can occur within the gameplay itself or outside it.

Educational serious games provide educational materials, by choosing which, the student himself/herself chooses the pace of learning. In most educational serious games, the cognitive and visual load of students is realized through the computer (or smartphone) screen. The game is an interface in which one or more loads are constantly increasing, each time increasing the level of difficulty and thus keeping the participants in suspense. In some games, there are high cognitive loads, since during the game the student must understand how the storyline develops and analyze the situation [23]. Such examples of mobile app-based serious games for education include math games [24], musical games for preschool children [25], digital games for teaching young children about programming [26], a gamified informatics course [27], improving children's procedural abstraction thinking skills in Scratch [28], a collaborative gamified quiz [29], game for fighting child obesity [30], or a serious game for carers of dementia patients [31]. For a systematic review of open educational games, see [32,33]. Each game is characterized primarily by a specific game context (the inner "world" of the game), which is built and maintained using special means, and assumes the presence of a set of positions and roles of the participants and, therefore, a controlled communication system, as well as special mechanisms that allow for generating game actions.

Our goal is to design, implement and launch an application designed for mobile devices, which will simultaneously visualize: the course of action of an algorithm (input data, change of data state, output data) and the source code responsible for these changes. The contribution of this paper is as follows: (1) providing a design of a mobile app implementing a serious game aimed at teaching how to solve common algorithmic problems in the JavaScript programming language, and (2) the evaluation of the game using the Technology Acceptance Model (TAM) and Technology-Enhanced Training Effectiveness Model (TETEM).

The organization of the remaining sections of this paper is as follows. Section 2 discusses the pedagogical and methodological backgrounds. Section 3 describes the game scenario, the design of gamification, and the implementation of the app. Section 4 presents the evaluation results. Section 5 presents the discussion. Finally, Section 6 presents conclusions and discusses future work.

2. Pedagogical and Methodological Backgrounds

In the traditional model of teaching programming at university [34], the leading role in the lecture belongs to the teacher. From him/her is required not only good knowledge of the training material but also the ability to put it to the audience: to present it in an interesting, figurative, and clear way. The most common way to visualize lectures is to prepare demonstration materials (presentations in MS PowerPoint). Using MS PowerPoint presentation materials allows for visually presenting the studied material in the form of static text or graphic information. Interest in the subject increases if, along with the systematic presentation of the material, including in the discipline program, the lecturer shows his understanding of the perspective on the development of the subject, shares the experience of his scientific developments, and can refer to the history and reasons that prompted the study of this or a different phenomenon.

The methodological backgrounds for the application of serious games for education are Game-Based Learning (GBL) [35,36], simulation gaming [37], and mobile microlearning [38]. Here, mobile microlearning means that the educational content is created for the small screens of smartphones, and is structured in small, self-contained bits of knowledge, which can be assimilated by students in no more than five minutes. The digitalization of information directly affects and modifies human mental activity in the process of education. The problem of the influence of a computer on human mental activity can be considered based on three main approaches established in psychology [39]: substitution theory, complement theory, and transformation theory. Substitution theory identifies the work of a computer program with the process of human mental activity. Complement theory is based on the theory of thinking, according to which a computer significantly increases a person's ability to process and perceive information. Transformation theory claims that the computer transforms human mental activity, and contributes to the emergence of new forms of mediation. The interactivity of a program is its ability to conduct a "dialogue" with the user, i.e., to respond to user-entered requests or commands. A feature of human–machine interaction is its belonging to a special type of communication called interaction. Interaction involves not only the exchange of information between the participants in the communication but also their joint activity. The system immediately reacts to commands and user requests (feedback), and allows the latter to determine and, if necessary, adjust their further actions.

Current approaches to enriching the traditional lecture with elements of entertainment and games include embedding computation in physical objects like cubes, etc. [40], developing tangible interfaces for teaching children about robot programming [41], or gamified quizzes and puzzles [42]. However, these games usually focus on young school children and teens, whereas they are considered as too simplistic by young adults such as university students. Our novelty is the development of a serious game for mobile devices, which is aimed at teaching university students how to solve common algorithmic problems in the JavaScript programming language, while simultaneously visualizing: the course of action of an algorithm (input data, change of data state, output data) and the source code responsible for these changes.

3. Materials and Methods

3.1. Pedagogical Models

In this paper, we have adopted a model of game-based learning from [43] (see Figure 1). When developing an interactive game, we followed the guidelines for integrating gamified learning in the classroom [44] as follows. First, we clearly define the pedagogical objectives, which are to acquaint the students with introductory concepts in programming. Next, we determine the technological competency of our target students. Finally, we identify the content to teach.

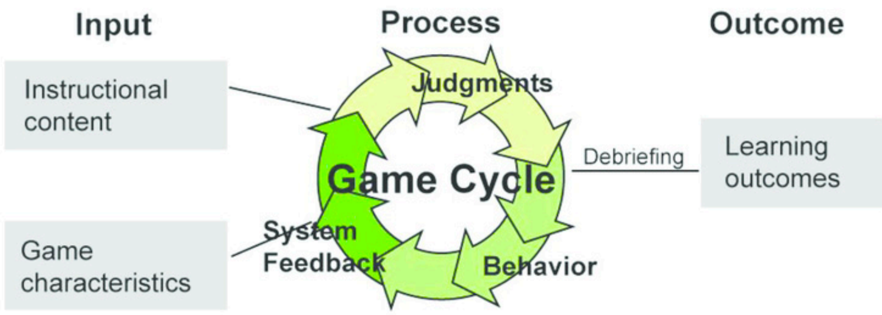

Figure 1. Model of game-based learning (adapted from [34]).

Our pedagogical model of the learning process based on the serious game (Figure 2) is based on 5 key elements, which interact in achieving a sustainable serious outcome while keeping the students engaged and motivated. The model starts with the element representing the pedagogical aims, i.e., the learning of the JavaScript (JS) programming language. Other elements such as adaptive learning [45] are used to support the achievement of this aim. Adaptive learning ensures the adaptiveness of learning through feedback, which constructs an individual learning path for each learner. As a result, gaps in knowledge are closed and the difficult topics are encouraged to be repeated for rooting the acquired knowledge. At the same time, adaptive learning ensures that the well-understood topics can be covered faster and without unnecessary repetition. Game mechanics are used to support such reinforcement of desired learning behavior in an engaging and motivating way. The effectiveness of the pedagogical process is evaluated using the TAM and TETEM, which allow for evaluating the effectiveness of the game-based learning process. Finally, in line with the current trends for interdisciplinarity and woke pedagogy [46], the digital game is placed within the context of ecology and sustainability issues, which promotes and encourages green thinking [47] to raise awareness of societal issues and provide diversity in education that transcends the direct needs of the programmer profession. Furthermore, the game, which can be played remotely and anytime on a smart user device (smartphone), fits well into the concept of 21st century online education [48], which is going to dominate the landscape of education in the post-COVID-19 world.

3.2. Design of Game Scenarios and Game Implementation

The game was developed by adopting the gamification pattern-based approach [49]. The designed interactive game has four major structural blocks: an authorization block (entering the game, choosing a topic), a game mechanics block (instructions, game rules), a learning block (user interface), and a game situation assessment block (analysis and evaluation). A schematic representation of the game flow is given in Figure 3.

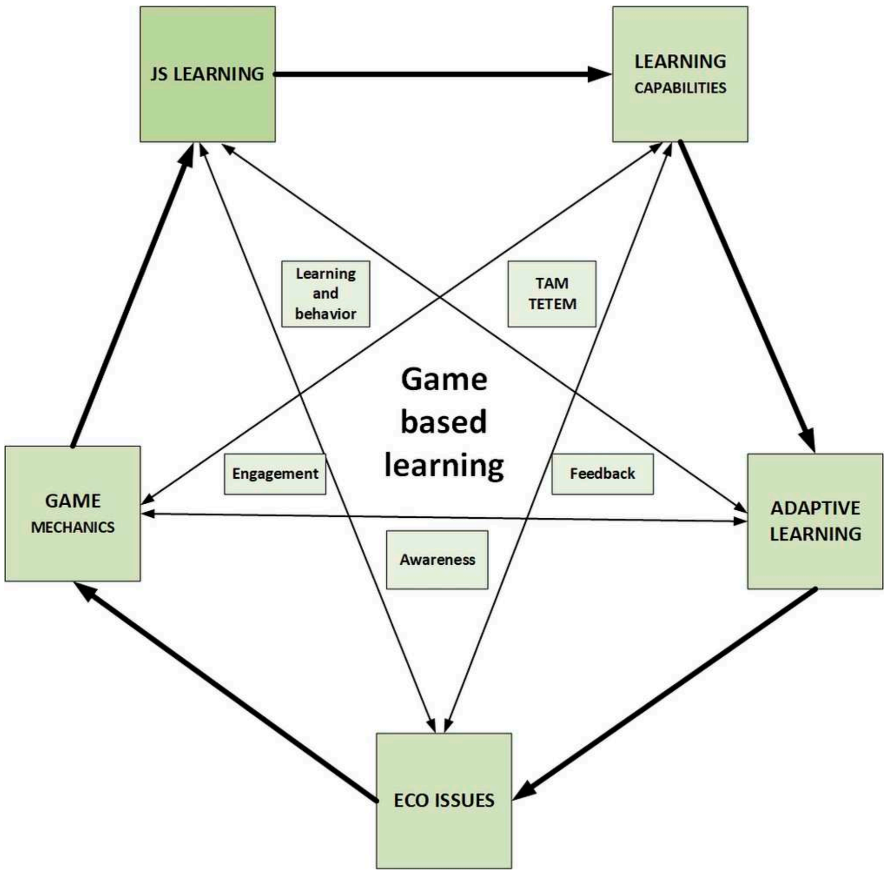

Figure 2. The pedagogical model of the learning process-based on serious game. TAM is Technology Acceptance Model. TETEM is Technology-Enhanced Training Effectiveness Model.

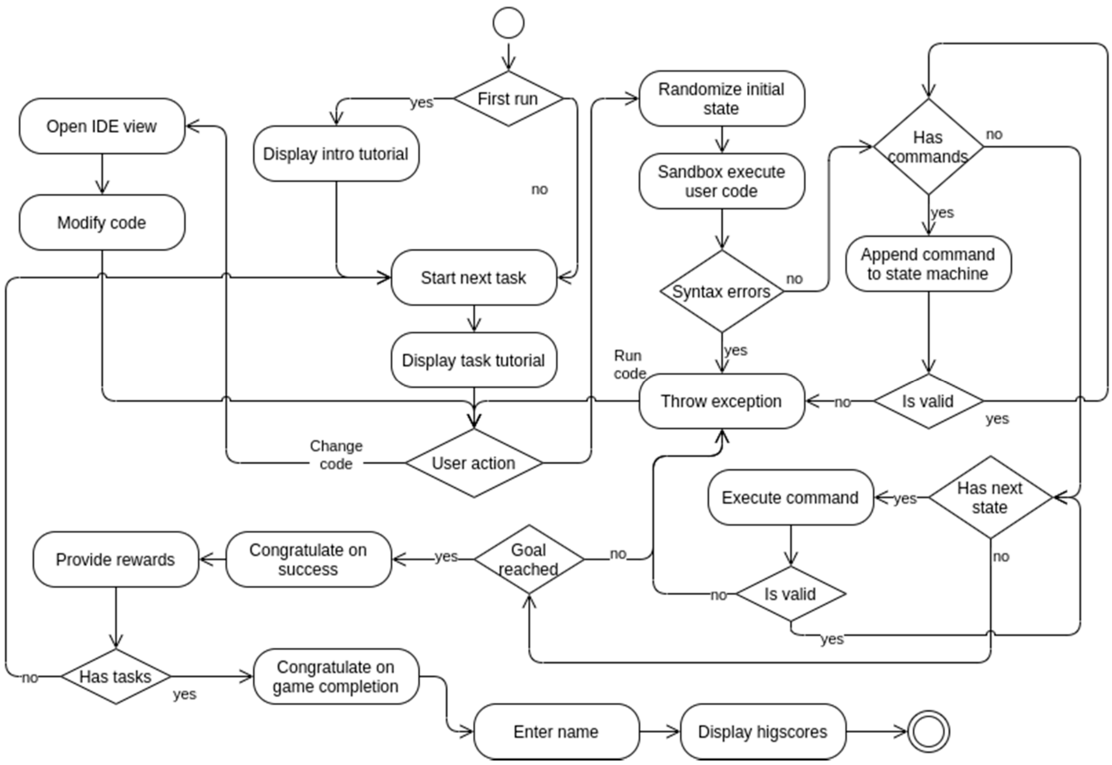

Figure 3. Schematic representation of the game flow. ○ is the start of the game. ◎ is the end of the game.

The story of the game is based on environmental awareness of ecological problems occurring in everyday life, while the direct (not-serious) aim is the prevention of city pollution in daily activities. The user acts as a commercial advisor having to solve puzzles to build an industrial quarter for the city to start generating income while avoiding excessive pollution, which decreases the game score. Successful implementation of programming-related tasks allows for increasing city revenue and the game score. The game is available online at http://algo-js.usz.edu.pl/.

3.3. Gamification of Programming Algorithms

Many studies [50,51] claim that problems in programming education arise due to the complexity of abstractions and concepts of programming such as variables, arrays, functions, or loops. To overcome this barrier for learning programming, the principles of visual programming, which focus on the use of visual abstractions corresponding to programming abstractions [52], are adopted. The selection of topics follows the list of suggested topics of an undergraduate computer science course by ACM Computing Curricula [53].

The concepts that our system supports are common programming algorithms: linear algorithms, branching (conditional) algorithms, iterative algorithms, search and sorting algorithms, recursion, tree raversal, and graph algorithms. We describe the gamification of these algorithms in more detail in the following subsections.

3.3.1. Linear Algorithm

Linear algorithms are algorithms which do not involve branching, i.e., there are no conditional statements. Examples of such algorithms are recipes, which describe how to complete a task by executing several steps. The case for such an algorithm is finding an exit through a maze of streets in a city. The idea is represented by the following image from the game's interface (Figure 4). Each command is evaluated and visualized in a loop. The algorithm finishes the execution if: the client is found (or the exit is reached), or the car object makes an invalid move. The visualization includes showing the truck position with a rotation related to the last command. Each step of a truck should be visualized as well. Several levels could be implemented. The difficulty of the task is managed through the maze complexity. The introductory level includes only one command and a very simple maze. Additional levels include using an increasing number of commands. In the highest levels, a maze is generated randomly, so that a student has to make a correct algorithm in one go.

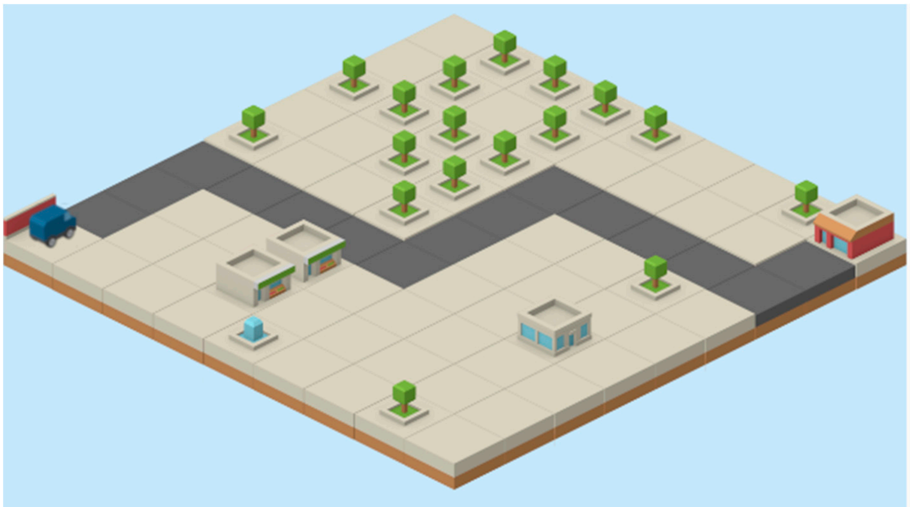

Figure 4. Illustration of a linear style algorithm by finding an exit through a maze of streets in a city.

3.3.2. Branching (Conditional) Algorithms

Branching refers to conditional statements, conditional expressions, and conditional constructs, which are dedicated to performing some computations or actions depending on the evaluation of the programmer-specified Boolean condition. To solve the task, a student has to write conditional statements including equals, not equals, less than, more than, less than or equal, and more than or equal, which are visualized as turning decisions at each city intersection (Figure 5). To reach the aim, the branching conditions must be written correctly.

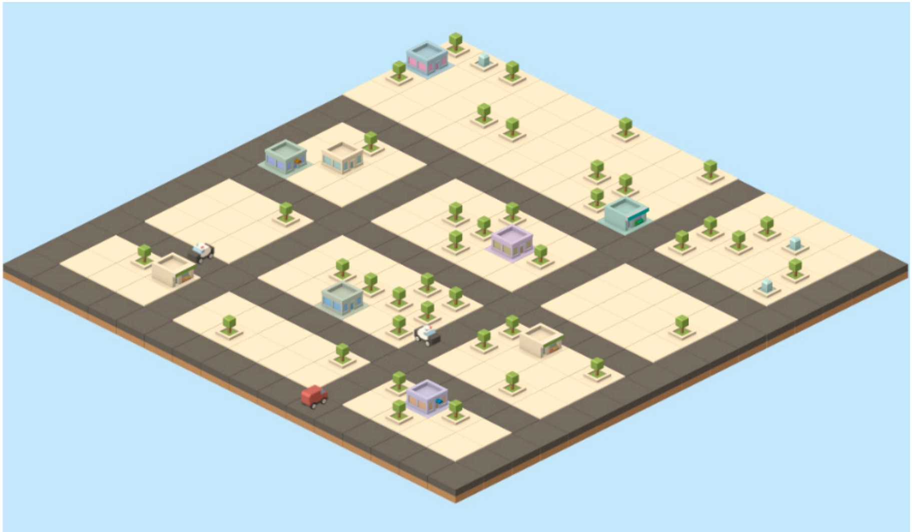

Figure 5. Illustration of a conditional algorithm—finding a correct route in the city streets.

A student will have to implement a function that will be tested with several sets of input data. Each command except the conditional statement is evaluated and visualized in a loop. The algorithm finishes if all test cases were successfully executed, or there was a mistake in a test case. There are three containers of different sizes and the task is to sort out several types of color-coded waste (green—bio, blue—plastic, red—construction waste, etc.) trucks to the appropriate waste dumps. Visualization includes moving a person to a container and dropping an item. Each step of a person's movement is visualized as well.

3.3.3. Iterative Sum Algorithm

A simple summation task which does not include arrays could be formulated like this: given a number n, find the sum of digits in all numbers from 1 to n. The sum algorithm normally involves a variable where the sum is accumulated (sometimes called an accumulator) and a loop that iterates within a given interval. The general case for such an algorithm is has an increasing number of objects which are moved to a container of a specific type and the sum of the objects in the container is displayed. The narrative of this case is that there are several parking places and the parking place number denotes how many cars it can contain. The task is to calculate the sum of the cars which could be placed in a given number of parking places.

Each command is evaluated and visualized in a loop. If the sum variable is equal to the previous sum plus the expected number of trucks, then the animation should start moving trucks to the big waste depot. The algorithm finishes if all trucks are moved to the empty waste deposit place, or there is a mistake and the sum variable is not equal to any possible combination. Visualization includes moving trucks to the waste deposit lot and showing the value of the sum variable.

3.3.4. Iterative Search Algorithm

The simple search task is to find a specific value of a specific item in a given range of values. In this case, we could use the waste truck scenario. Given the array of random truck numbers assigned to waste deposit places, we need to find a maximum (or a minimum) number of trucks in a waste depot (Figure 6). A student will have to implement the minimum or maximum finding functions. That function receives an array of numbers called trucks which has to be investigated and the minimum or the maximum number of cars is found.

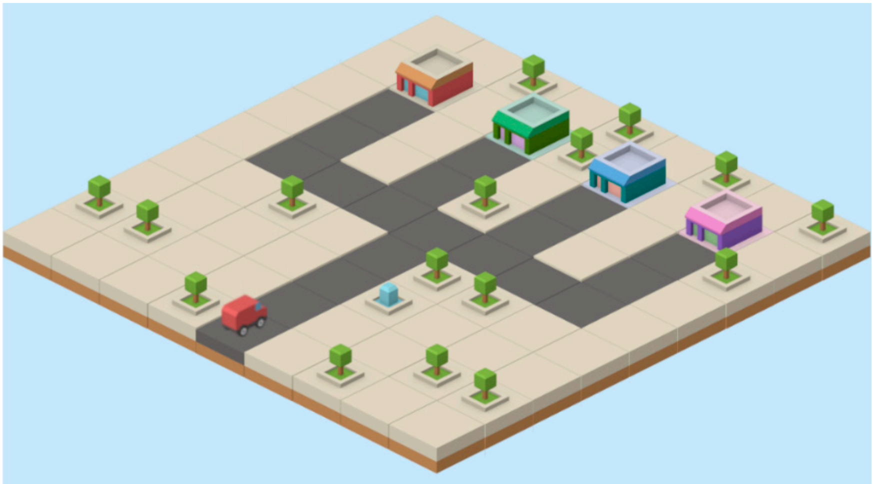

Figure 6. Illustration of an iterative search algorithm—finding the correct waste deposit lot.

Each command is evaluated and visualized in a loop. Each item from the cars array is evaluated against the current min or max variable. The algorithm finishes if the loop finishes successfully and the min/max value is found, or there is a mistake in the provided solution and the min/max value is not found. The visualization includes comparing the current state of the truck array to the minimum or maximum value found before that iteration.

3.3.5. Iterative Sorting Algorithm

Sorting consists of ordering a list of objects according to the value of a specified property. We start familiarizing the student with this concept from the simplest (and less efficient) algorithm called *bubble sort*. In this case, we could use the building scenario. Given a set of city buildings, we need to sort them according to their heights (number of floors) as larger buildings pollute more.

A student will have to implement the building sorting function. That function receives an array of heights called buildings which have to be sorted in increasing order (see Figure 7). Each command is evaluated and visualized in a nested loop. The users' data array is investigated in each iteration, and if there is a change in an array, then the animation of swapping two players starts. The algorithm finishes if the loop finishes successfully and the data are sorted in increasing order, or there is a mistake and the returned data do not match the sorted data. Variations of the implemented algorithm may include changing the sorting direction.

The recursion is implemented by using functions that call themselves from within their code. The Fibonacci recursive algorithm, which generates the Fibonacci number sequence, is used to visualize the recursion. The task for this scenario is to implement a function that takes one parameter (n) and returns the corresponding Fibonacci number. The scenario narrative includes trucks and waste deposit places. The idea is that every newly built waste depot should be able to contain the waste trucks from the waste deposit places built before. A student has to implement the Fibonacci sequence calculation function. The calls to the Fibonacci function are visualized as a call stack. Numbers are visualized as trucks that appear after the result of the function call is returned. The algorithm finishes if all test cases were successfully executed, or there was a mistake in a test case.

Figure 7. Illustration of sorting algorithm using the building ordering scenario (the higher building is a more polluting building).

3.3.6. Recursion

3.3.7. Tree Traversal Algorithms

Traversal is visiting all the nodes of a tree data structure and executing the associated actions. Generally, we traverse a tree to find and access an item stored in the tree data structure. To visualize tree traversal algorithms, we use the city maze scenario. The maze is organized as a tree that has several levels. Given the picture, the student will have to create a tree data structure and to implement the chosen tree traversal algorithm. Thus, the picture needs to be transformed into a tree. The city maze root node is a maze itself. It has two children—greenery and structures. Greenery contains parks, lakes, and fields. Structures contain buildings, roads, and parking places. Each node has a title, coordinates, and children. A student needs to create a tree data structure and construct the specific tree of a given city maze. Initially, the game app shows a semi-hidden maze (a semi-transparent layer is shown over the maze). According to the data structure and the tree construction code created by a student, the app opens specified tiles. The task will be completed if all tiles are opened.

3.3.8. Graphs—Shortest Pathfinding Algorithm

A graph is an abstract data type used to model a set of connections. To find the shortest path, the city maze needs to be transformed into a weighted graph with the weights corresponding to the distance between intersections. The most important/well known algorithm to find the shortest path in a weighted graph is Dijkstra's algorithm. The task is to find an exit through the maze of streets in a city. That image needs to be transformed into a graph. The game narrative is a truck driving through the city to get some building materials or to pick up waste. To solve this task, a student needs to create a graph structure. For that purpose, the street intersections need to be named and visualized in a city street maze. According to the graph created by a student, the game visualizes the connections as lines and numbers assigned to these connections as weights. The connections are drawn in a green color if the connections exist in the reference graph. Otherwise, the student graph connections will be drawn in red. The app draws the weights in a green color if the weights are accurate compared to the reference graph. Otherwise, the student graph weights will be drawn in red.

3.4. Evaluation Measures

To assess the effectiveness of the game in teaching the introductory concepts and the construct of programming logic and thinking, a pre-test and the post-test were performed and analyzed. All tests were created by computer science teachers. Each test (pre-test and post-test) included the same topics of programming and covered the same content of materials and degree of complexity.

The pre-test assessment was done before the start of the course to find the knowledge of programming constructs and abstractions among students before the course, while the post-test was taken by the students after the course. Each group was given 10 exercises to solve within a time limit of 90 min. After the end of the course, the students were given a post-test, which was delivered in the same way as the pre-test. Finally, the overall assessment was done by comparing the evaluation scores obtained during the pre-test and post-test to find the improvement in the student knowledge.

To validate the developed game, a survey was conducted using the Technology Acceptance Model (TAM) [54]. The TAM was already used for evaluating the use of gamification for serious purposes [55]. The questionnaire had 10 questions that address five elements (two questions per each element of the TAM) to validate: perceived usefulness (PU), perceived ease of use (PEU), attitude towards use (ATU), intention to use (IU), and perceived enjoyment (PE) as an external factor. PU evaluates how useful gamification is for improving professional competencies. PEU is an indicator that measures users' behavioral attitudes towards the ease of technology use. ATU is the degree to which a student perceived desirable feelings related to the use of a serious game for learning. IU measures the intention to use a serious game for learning. PE evaluates the hedonic enjoyment of students while using the serious game. Each item is assessed with a 7-point Likert-type scale from 1 (strongly disagree) to 7 (strongly agree). For the evaluation of the internal consistency of survey results, we use Cronbach's alpha, which verifies the reliability of the measurement scale used.

We also adopted the Technology-Enhanced Training Effectiveness Model (TETEM), which was created to analyze the adoption of virtual worlds in organizational training [56], but later adopted to evaluate the effects of gamification [57]. The model evaluates experience with videogames (EVG), attitudes toward game-based learning (AGBL), control valence (CV), and gamified valence (GV), and can be used to assess the relationship between gamification and training. EGV refers to the amount of time spent playing different games, and identification with gaming culture. Valence refers to the anticipation of gain from learning, which in turn influences student reactions, outcomes, and the degree of knowledge transfer. Each item is assessed with a 5-point Likert-type scale from 1 (strongly disagree) to 5 (strongly agree).

The results of the survey are evaluated using statistical testing (Shapiro–Wilk normality test, Mann–Whitney U test) and correlation analysis (Pearson correlation coefficient). The Shapiro–Wilk normality test is used to test the hypothesis that the data are normally distributed. The Mann–Whitney U test is a nonparametric test commonly used to compare outcomes between two independent groups.

Pearson correlation is a statistical measure that assesses the linear correlation between two variables. We used it to check the relationship between the elements of the TAM and TETEM.

4. Results

4.1. Participants and Educational Setting

The participants consisted of 54 undergraduate students at Kaunas University of Technology (Lithuania). The sample was 83.4% male and 16.6% female (mean age = 19.43, SD = 1.17). The survey was approved by the Institutional Review Board at the Faculty of Informatics, Kaunas University of Technology. All participants voluntarily agreed to take part in the survey. Answers were fully anonymous, and no personal data were collected, while only aggregate information was later used.

Based on the prior academic results, the participants were randomly split into two groups (game group and control group) to maintain academic balance. Both groups attended a traditionally delivered (with PowerPoint-based lectures) programming course, but the game group was introduced to the game and encouraged to play it.

For the TAM survey, we used the original TAM questionnaire as in [58]. For the TETEM survey, we used the questionnaire presented in [59], in which we only replaced "video games" with "computer games", and "work training" with "programming training".

4.2. Results of Performance Evaluation

The results of the pre-test evaluation were explored using skewness and kurtosis values, which satisfied the normality requirement, suggesting that any diversity in the students' background knowledge originated from a normally distributed population. To support this assumption, a Shapiro–Wilk normality test was performed to examine the distribution of scores achieved by students. The results indicated that the scores may have been normally distributed (W = 0.9263, p-value = 0.2158; W = 0.9366, p-value = 0.2267, for both groups, respectively).

In our case, the Mann–Whitney U test was used to compare the background knowledge between students from both groups, showing that there was not a statistically significant difference ($p = 0.08$) between students from the game group (M = 6.56, SD = 1.24) and the control group (M = 6.65, SD = 1.38) in the pre-test evaluation. The control group achieved slightly better results than the game group in the pre-test evaluation. In the post-test, there was a statistically significant ($p < 0.001$) difference between students from the experimental (M = 8.41, SD = 1.29) and control (M = 7.62, SD = 1.16) groups according to the Mann–Whitney U test (Figure 8).

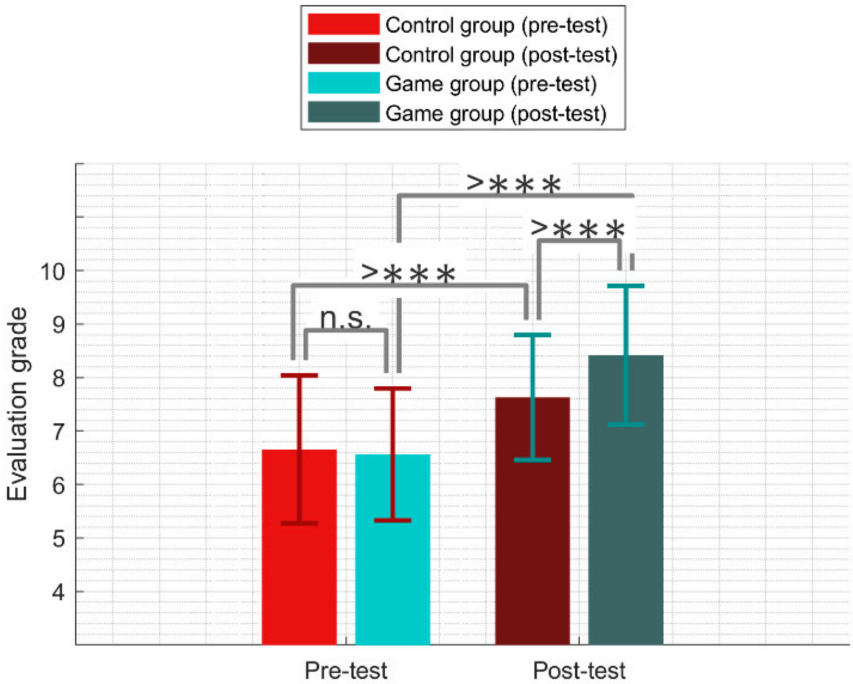

Figure 8. Summary of pre-test and post-test evaluation of game group and control group. ***—statistically significant ($p < 0.001$). n.s.—not significant ($p > 0.5$).

Moreover, the game group has a learning gain (MD = 1.855) greater than the control group (MD = 0.969) between the two evaluations, while the statistical significance of this difference was confirmed by the Mann–Whitney U test ($p < 0.001$). The results are summarized visually in Figure 9.

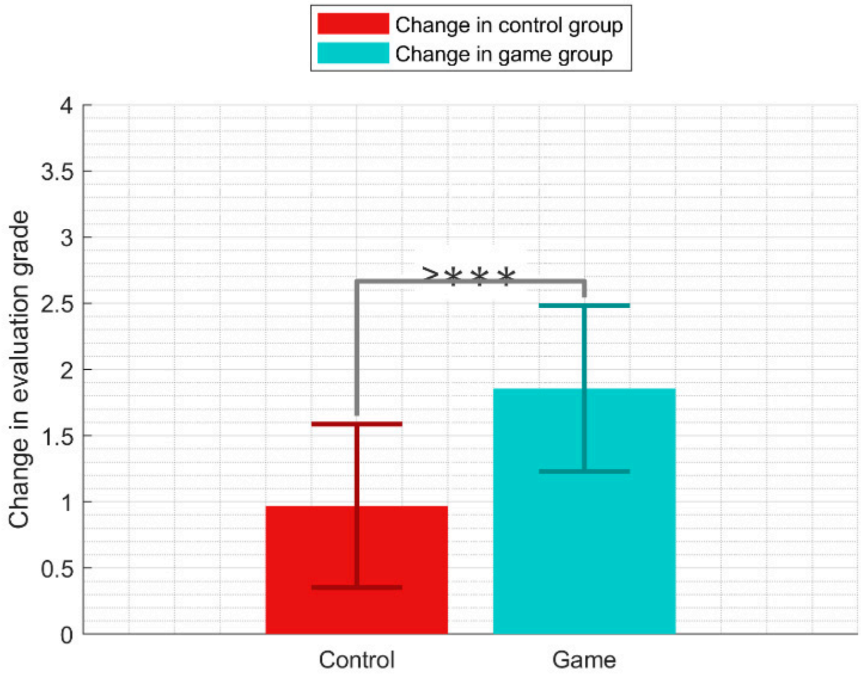

Figure 9. Change in evaluation scores of the game group and control group between pre-test and post-test. ***—statistically significant ($p < 0.001$).

4.3. TAM

For the evaluation of the internal consistency of TAM responses, we use Cronbach's α, which is equal to 0.89. Note that $\alpha \geq 0.80$ is considered good.

Pearson correlation was calculated to check the relationship between the analyzed TAM elements (see Figure 10). A positive correlation was observed between PEU and PU ($R = 0.516$, $p < 0.001$), between PU and ATU ($R = 0.798$, $p < 0.001$), between PU and IU ($R = 0.417$, $p < 0.01$), and between ATU and IU ($R = 0.446$, $p < 0.01$).

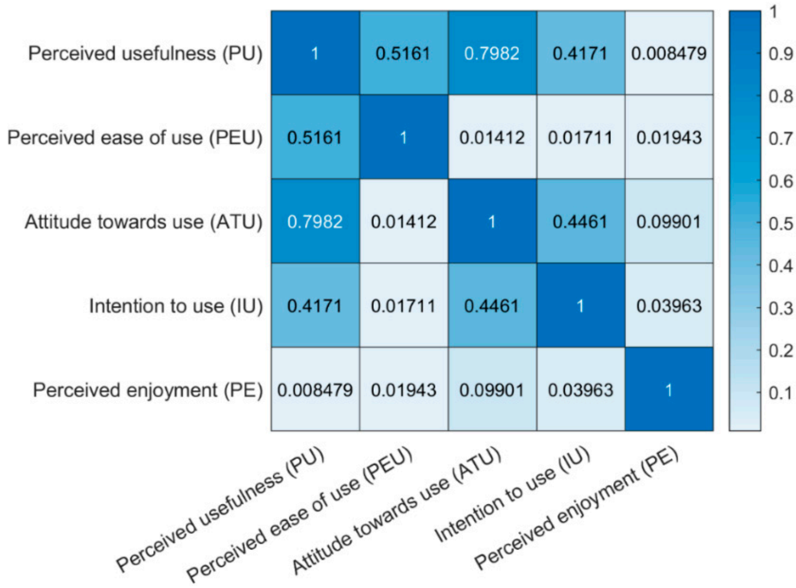

Figure 10. Pearson correlations between the elements of the TAM.

4.4. TETEM

For the evaluation of the internal consistency of TETEM responses, we use Cronbach's alpha. The result is $\alpha = 0.96$. Note that $\alpha \geq 0.80$ is considered good.

Pearson correlation was calculated to check the relationship between the analyzed TETEM elements (see Figure 11). The statistically significant correlation was noticed between EVG and GV ($R = 0.60$; $p < 0.001$), and AGBL and GV ($R = -0.38$, $p < 0.01$). The results of the survey support the claim that a gamified learning experience leads to higher valence, which provides for a causal relationship between the use of gamification and the learning outcomes.

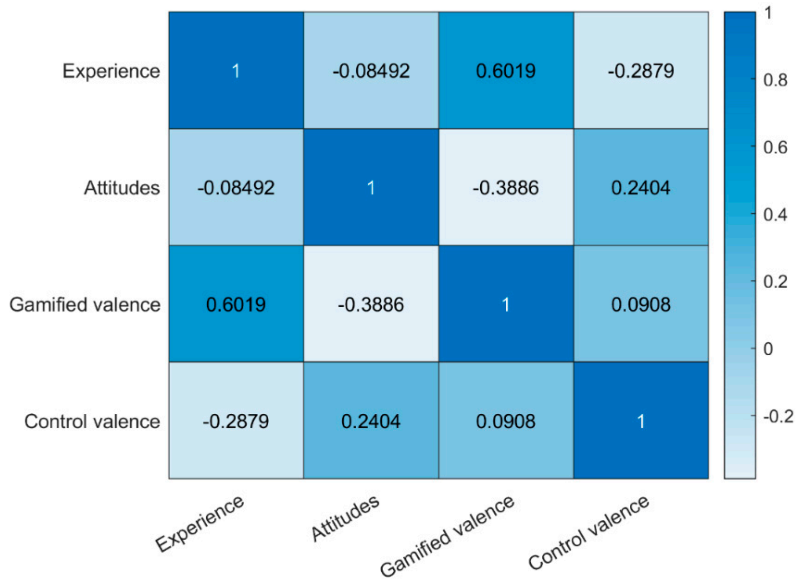

Figure 11. Pearson correlation between the elements of the TETEM.

5. Discussion

Game-based learning is a process both unpredictable and difficult to manage. Its course is affected by some factors, which are very difficult to calculate, and even more so to assess their mutual influences. However, the systematic and purposeful use of game methods can give certain results, both in changing the basic qualities of a person and in the effectiveness of educational activities. So, we can discuss gamification as a new way of organizing training, which has a huge pedagogical potential. Inherent mechanics of gamification allow you to run the very highest level activity, which is the root cause, the source of the child's activity, which has a creative character [59], with how to stimulate subjective activity, but does not remove a learner from the reality.

Elements of gamification make the standard university course more interesting. For example, game mechanics can motivate a student to do homework and solve tests, and if the topic is too complex, then simple programming examples with gamification will help to better understand and learn the material for the future. A large programming course, in which students risk getting lost, can be supplemented with a serious game—such a tool provides an incentive for the student to complete the course. Incentive badges or points for different actions when completing practical programming tasks will motivate the student to pass the course on time. Among other things, game mechanics make the learning activities themselves more attractive, which was confirmed by the results of the TETEM survey (item "gamification valence"). This study is the first study that had adopted the TETEM questionnaire for evaluating a serious game for teaching programming.

On the other hand, the TAM model is well known and has been used for evaluating games several times. Wang et al. [60] used the TAM to evaluate a mobile game, which supported students in learning color mixing in design education. They found a significant correlation between PEU and PU, between PU and ATU, and between ATU and IU. Onashoga et al. [61] developed a 3D game-based learning approach for increasing awareness of phishing attacks. The study has found that all relationships between PEU, PU, ATU, and actual usage of the system (AUOS) were significant and positive. Giannakoulas and Xinogalos [62] developed an educational game for teaching simple programming concepts to primary school children. They used the TAM to evaluate the game but did not perform an analysis of relationships between the TAM concepts. Therefore, our results of evaluating the developed game using the TAM model are largely in agreement with the results achieved by other studies.

Thus, the main principle of gamification is to ensure that constant, measurable feedback from the student is received, which provides the possibility of dynamic adjustment of his/her learning behavior to achieve adaptive learning, and, as a result, the rapid development of all the functionalities of the serious game application and the gradual mastering of educational material. The latter aspect is especially relevant in the era of COVID-19 lockdowns, which have disrupted the usual flow of teaching in schools and universities, while current modes of remote learning, which were hastily enacted, lack feedback mechanisms to monitor the learning process effectively, raising new challenges for educators and serious game designers [63,64]. The mobile game, such as the one presented in this paper, can be used to sustain student–student and student–teacher ties in the learning process by putting the student in the learning-oriented gaming community. The emergence of educational serious games also changes the pedagogical position of the teacher and creates conditions for the development of new modes of remote education for the COVID-19 world. These new modes based on mobile applications, including mobile games, can be used to bridge the digital divide in teaching information technologies [65]. However, the usefulness of a serious game for improving the learning performance among disenfranchised groups of learners still requires further research.

The adoption of serious games also has limitations. Our approach is limited to a single course in the programming study curriculum at the university level. Developing games for a different study course (especially for a course attended by non-technologically oriented students) may require adopting a different set of solutions. Designing a game for school or high school students also may require adjustment of the pedagogical model. Finally, when evaluating our game, we followed a closed-world assumption, as the students did not use any games for learning in other courses. If a serious game-based learning approach were adopted more widely, for example, at the study program level, and the students would use the games in many courses, and the attractiveness of a serious game as an educational tool per se may decrease.

Following our experience of using the game in the teaching process, we outline the following limitations of the application of serious games in education as follows. External rewards, such as points, are certainly necessary, but the internal motivation of students to study is more important [66]. The student must clearly understand that it is the educational achievements for which the awards (badges, points, etc.) are given. There is a risk that gamification can undermine behavior psychologically as some students may focus solely on receiving awards rather than on the educational process itself.

6. Conclusions

In this paper, we described the use of our developed interactive mobile application as a serious game for learning how to solve common algorithmic problems in the JavaScript programming language. The game was validated using the TAM and TETEM. The results of the TETEM survey supported our assumption that gamified learning experience leads to higher valence, which supports the positive relationship between the use of gamification and the learning outcomes. On the other hand, the TAM survey revealed positive relationships between perceived usefulness (PU) and perceived ease of use (PEU), as well as between attitude towards use (ATU) and intention to use (IU), which support the use of gamification as a tool for improving professional competencies, and the student intention to use the developed serious game for learning.

Future work will focus on the repurposing of our approach for other fields of education beyond programming and computer science.

Author Contributions: Conceptualization, J.S. and R.M.; methodology, J.S., R.M., T.B., and R.D.; software, A.K.; validation, J.S., R.M., T.B., and R.D.; formal analysis, J.S., R.M., and R.D.; investigation, J.S., R.M., A.K., T.B., and R.D.; resources, J.S., R.M., and T.B.; writing—original draft preparation, J.S., R.M., T.B., and R.D.; writing—review and editing, R.M. and R.D.; visualization, R.M. and A.K.; supervision, J.S. and R.M.; project administration, J.S. and R.M.; funding acquisition, J.S. All authors have read and agreed to the published version of the manuscript.

Funding: Supported by a grant from the Cooperation Fund Foundation within the "Paths of cooperation—support for entities implementing international cooperation" project co-financed from the European Social Fund under the Operational Programme Knowledge Education Development.

Conflicts of Interest: The authors declare no conflict of interest.

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Article

The Case of a Multiplication Skills Game: Teachers' Viewpoint on MG's Dashboard and OSLM Features

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Citation: Leonardou, A.; Rigou, M.; Panagiotarou, A.; Garofalakis, J. The Case of a Multiplication Skills Game: Teachers' Viewpoint on MG's Dashboard and OSLM Features. *Computers* **2021**, *10*, 65. https://doi.org/10.3390/computers10050065

Academic Editors: Carlos Vaz de Carvalho and Antonio Coelho

Received: 4 April 2021
Accepted: 13 May 2021
Published: 17 May 2021

Abstract: Educational games and digital game-based learning (DGBL) provide pupils interactive, engaging, intelligent, and motivating learning environments. According to research, digital games can support students' learning and enhance their motivation to learn. Given the central role teachers play in the learning process, their perceptions of DGBL play a significant role in the usage and effectiveness of game-based learning. This paper presents the main findings of an online research on primary school teachers' attitudes toward DGBL. Furthermore, the research investigates teachers' opinions about the functionalities provided by the implemented Multiplication Game (MG) and the newly incorporated teacher dashboard. The MG is an assessment and skills improvement tool that integrates an adaptation mechanism that identifies student weaknesses on the multiplication tables and in its latest version also supports a strong social parameter. Students can be informed about their own progress as well as the progress of their peers in an effort to examine if social interaction or competition can increase players' motivation, which is a subject that raised some concerns in the teaching community. The paper describes the functional options offered by the MG dashboard and documents the outcomes of an online survey conducted with the participation of 182 primary school teachers. The survey indicated the potential usefulness of MG and the benefits it can offer as a learning tool to improve pupil multiplication skills and help teachers identify individual pupil skills and difficulties and adapt their teaching accordingly. The analysis applied has found a correlation between teachers' perceptions about MG and their view on using digital games in general.

Keywords: digital game-based learning; media in education; multiplication game; digital games usefulness

1. Introduction

According to Prensky [1], what allures nowadays children to participate in video and computer games is neither violence nor their subject but the provided learning. Children similar to all humans enjoy learning when the notion of obligation is missing. Through modern computer and video games, game players not only become familiar with ways to use games and act inside the game theme and plot but are also offered opportunities of metacognitive learning (p. 2):

> "to take in information from many sources and make decisions quickly; to deduce a game's rules from playing rather than by being told; to create strategies for overcoming obstacles; to understand complex systems through experimentation"

Furthermore, players learn to interact and cooperate with others while developing a social consciousness.

Today's game-players at their mid-school age are already capable of comprehending and possess a remarkable fluency in doing many complex things (e.g., reasoning, building, flying); therefore, the typical school curriculum is considered rather unattractive and disengaging. Consequently, it is crucial that teachers try hard to keep up with their students' digital pace and even to embrace their online capabilities through designing appropriately the whole teaching form [1]. Furthermore, during the COVID-19 pandemic, digital educational games have earned a significant role through distance learning settings (either synchronous or asynchronous) deployed for considerable periods of time in educational systems around the world. Educational games and digital game-based learning (DGBL) offer pupils learning environments that are interesting, engaging, intelligent, adaptive, motivating, and interactive, where pupils can communicate their knowledge, experiences, feelings, and thoughts [2–4].

This paper, starting from game-based learning theory attempts to offer an insight of teacher perception and acceptance of digital games in general, and the Multiplication Game (MG) in particular. MG is a digital assessment tool, and part of its usefulness results from the incorporated logic of DGBL. Furthermore, it is designed to promote flow experience that fosters learners' enjoyment and concentration. Student motivation is developed by incorporating the Open Learner Model notion, as parts of the underlying user model are exposed to pupils in a graphically simplified form. Moreover, MG shares a social aspect as the learner model does not open exclusively for the particular pupil but also for the teacher and class pupils through adequately designed views. This study focuses on revealing pupil's information to the teacher via a dashboard where the teacher can monitor the progress of individual pupils and the whole class on multiplication skills. The objective of the conducted survey was to investigate the perceptions teachers have toward the opening of pupil progress data to the pupil they concern and to peers, and also their attitude toward the benefits and support MG can provide to their teaching. Moreover, the survey recorded the teachers' views of the MG in relate with their views on DGBL.

2. Digital Games and DGBL

Undoubtedly, modern pupils impose high demands on the technological aspects of their learning as they do not consider traditional educational approaches as interesting and require up-to-date learning environments and tools. Game-based learning is the pedagogical approach that makes use of games offering pupils the opportunity to take part in the educational process and material in an active and enjoyable way [5]. Game-based learning comprises the design and development of game activities targeting interactive learning and supporting pupils to gradually apprehend concepts and be guided toward a final goal [6]. At the same time, pupils are experiencing feelings of achievement, reward, and progression. Game-based learning can be utilized as a teaching method because through game content and plot, pupils can explore the various game parts, using them as ways of knowledge acquisition and skills enhancement [7,8]. Based on similar observations, Prensky [1] supported that educational software design should take its shape using game design methods and techniques. This belief is widely respected, and its popularity is growing [4]. Nevertheless, educators should be cautious about the frequency of deploying digital games in their teaching practice, as many of today's children already make excessive use of digital games, which leads to problematic habits such as lower physical activity, fewer social interactions, poor sleep patterns [9], or even substance addiction symptoms e.g., craving, mood changes, tolerance, and salience [10,11]. Still, the potential benefits of digital educational games outnumber their side effects and cannot be considered as a reason to exclude digital games from the classrooms.

Digital games span a wide range of categories, use a variety of digital technologies (e.g., computers, (handheld) consoles and mobile devices) [12], and their popularity is steadily rising [13,14]. Digital educational games are defined as "computer-assisted instructional tools and techniques in which skills and chance are combined and implemented on previously acquired information and experiences developing thus, engaging and immersive learning experiences in order to achieve specific learning goals, outcomes and experiences" (p. 120) [7]. Moreover, digital educational games support adaptability and foster situated learning environments where students through playing obtain and exchange knowledge and skills [2,15]. As digital games provide a virtual environment, they support students to overcome the limitation of physical space and offer hands-on access to learning materials [16]. According to Li [17], digital game creation and the engagement in them can result in active students, which will therefore lead in developing 21st century skills and supporting more effective and thorough curriculum understanding. Furthermore, according to [18], digital games help players develop skills such as "critical thinking and problem solving, teamwork and communication, creativity and innovation, and technology proficiency" (p. 421). Through digital gaming, pupils that initially possessed only the ability of applying pre-arranged solution strategies are gradually guided to develop the ability to comprehend original solution strategies [19]. Digital games can offer "opportunities for investigating and understanding real-world situations" (p. 24) [14]. According to [4], they provide an effective and motivational approach to support pupils' learning, while they can significantly improve knowledge transfer, increasing student enjoyment and interest on the particular subject.

According to [7,20], digital educational games when used as a teaching and learning tool can lead to:

- Promotion of pupil engagement, learning motivation, enjoyment and eagerness [1,21–23],
- Improved academic attainments and socialization of pupils [24,25],
- Increase of higher-order thinking skills, development of critical thinking, and promotion of cooperation among peers (i.e., classmates) [26,27],
- Positive influence on pupil creativity, problem-solving skills, spatial ability, and conceptual understanding [28,29].

Research studies support that game-based learning can be even superior to traditional classroom instruction as it enhances the motivation to learn, while offering opportunities to explore and acquire new knowledge and skills [8,30,31]. DGBL is a student-centered learning approach that unites digital games with educational material to provoke pupils' interest, while they are given the opportunity to empower their learning efficacy. As a result, pupils face knowledge acquisition and education in general, positively. Games designed according to these principles give pupils the chance to practice their skills in a virtual and safe environment, enhance collaboration, promote communication, and develop cognitive and soft skills [7].

3. Teachers' Attitude toward Digital Games

Shifting from the traditional form of teaching to teaching that includes using digital educational games in the classroom is considered to be a significant change [32]. According to Fullan [33], the implementation of an educational change is determined by three factors: (1) the characteristics of the change (e.g., if the change is useful, practical, and not complicated or long), (2) local characteristics (the district, the community, the principal, the teachers, etc.); and (3) external factors (government, other agencies, etc.) [32]. The adoption and the effectiveness of game-based learning depend largely on the grade of acceptance by classroom teachers [34,35], as they can be considered the true change agents of the schools [36]. Therefore, it is crucial to obtain an insight on teachers' perceptions and beliefs that guide their decision-making process. If teachers have negative perceptions about using DGBL, this can proved a significant obstacle against technology integration and against using digital games for learning [37,38].

Among models that examine and predict teachers' behavior stands out the Technology Acceptance Model (TAM) [39]. According to the TAM model, the acceptance of any technology can be predicted by (a) its perceived usefulness and (b) its ease of use. Furthermore, the TAM model highlights the correlation between these two factors: a technology is considered to be more useful if it is easier to use. In the field of educational research, it is observed that teachers will use a technology in the classroom, only if they are convinced about the advantages (on an administrative and teaching level) this technology can offer [40].

In an effort to summarize the main findings from studies such as [37,41–43] on digital games' adaptation in formal education, major points can be categorized under the following three axes:

1. Teachers' perceptions of the value of incorporating digital games in the classroom. More analytically according to teachers' beliefs, the main reasons to use digital games in the classroom are the following:
    - To enhance student motivation [3,42,44–47]
    - To support students' acquisition of knowledge and cognitive skills [42,44,45]. These beliefs regarding learning opportunities have the strongest direct effect on teachers' intentions to use games [38,48]
    - To offer students a safe learning environment where the consequences of failure are smoother [49]
    - To empower students' activeness [48],
    - To offer students feedback on their learning skills and actions [48],
    - To visualize students' progress for them to watch [48],
    - To propose additional learning material or a reward [37],
    - To entertain students [37],
    - To support evolvement as digital games are considered 'the future' (teachers support the belief that the adoption rate of game-based learning will continue to speed up in the very immediate future [37]).
2. Teachers' acceptance that games play an important role in their teaching procedure. Acceptance of digital games by teachers depends on many factors:
    - Teachers who experience playing games in their spare time are interested in the idea of digital games in their teaching process [45,50–52], while teachers' ability to effectively deal with new technologies does not necessarily imply that they support the idea of digital games in the classroom [37,45]
    - Degree of relevance (according to teachers) games have to their educational practice [34,41,44,51]
    - Usefulness and learning opportunities offered by the game [37],
    - Aspects in the social environment of teachers (students, colleagues, principal) [37,50,53],
    - Teachers' own experience, which has convinced them about the positive consequences of technology [48],
    - Pupil competition during game play [47], as this can be a reason for using games in the classroom [48,54].
3. Teachers' perceptions on barriers against using games in the classroom. The main factors that discourage teachers from using digital games may be the following:
    - Lack of time and technical issues [34,47,52],
    - Inflexibility of the curriculum or fixed class schedules [32,52], that makes teachers feel restricted and unwilling to try non-conservative ways of teaching,
    - Perceived negative effects of gaming e.g., addiction, emotional suppression, repetitive stress injuries, relationship issues, social disconnection [32],
    - Unprepared students [32] that delay teaching, as without adequate preparation at home, students cannot cope with the subject and concepts, and therefore, they deprive the class of the opportunity to play games or the teacher needs to consume teaching time for repeating the same teaching material,
    - Absence of supportive materials to help teachers find the suitable digital game that is compatible with the subject and the class level and also offers proper usage instructions [29,32,52],
    - Limited budgets [32] that lead to poorly equipped computer school labs, etc.,
    - Teaching experience may affect the type of limitations teachers consider when they think about using games in the classroom [32,34], as older teachers are less willing to try non-traditional ways of learning due to their poor or incomplete technology-related skills [29,52],
    - Classroom management issues [41] that can vary but take away the opportunity from the teacher to deal with issues such as the adoption of digital games,

- Poor learning opportunities of the available games [34,41],
- Complexity of using games in the classroom, as access to required devices is required (PCs or smart devices) with the risk of distracting pupils from the teaching goals, although its relation to the other factors remains unclear [34,38,49,50],
- Teachers' own poor efficacy in using the technologies, in combination with anxiety toward scenarios of failure [52].

4. Adaptiveness and Open Learner Modeling

In the game world, it is crucial for a player to face challenges that are in close correspondence with individual skills' level. If the challenge is higher than the player can handle according to own skill level, then the player can feel anxiety or be discouraged. On the other hand, if the challenge is much lower than the player's skills level, it is possible that the player will feel bored and not engaged [55]. Adaptive are the games that possess an internal mechanism that stores data for every player individually and therefore can make inferences that match the needs and preferences of each player. If apart from maintaining data about the learners and their interactions, some of these elements are also exposed in a suitable way, a connection is set up between adaptive educational gaming and open learner modeling (OLM). OLM was introduced as a notion in the research field of intelligent tutoring systems and adaptive learning environments with the aim to support personalized instruction to learners. At first, adaptive systems did not give learners the chance to access the data stored in their learner model, but things changed when researchers and educators supported through experiments the educational gain that derives from such a revealing [56]. It was proved that by offering learners an insight into specific parts of their own user model, they could use this feedback to self-assess and also reflect on their current skills and competences, organize more effectively their learning, apprehend the system's adaptation decisions, and also demonstrate greater motivation to learn and improve [57–59].

Social OLM (OSLM or OSSM) is an extension of OLM [57,60], and its basic idea is to expose elements from a learner's model also to others, apart from the particular user the data refer to, e.g., instructors, peers, and parents. OSLMs can intensify OLMs' cognitive aspects via social aspects, as learners are given the opportunity to explore other individuals' model or summative information of a peers' group and support them through suitable content topics [61].

Different studies [62,63] support the opinion that when accessing peers' models, learners achieve a wider coverage of topics in the system and higher rates in self-assessment problems. In fact, the OSLM notion is in agreement with past research in the domain of social navigation, which can be utilized in order to guide users through the learning content by revealing other learners' paths and therefore replace knowledge-based guidance [64]. Another contribution of OLM and OSLM is that they contribute in promoting engagement to learning environment and content [61,65].

The choice of which information the user will access and in what way it will be represented are both central issues, as OLM and OSLM will not meet its practical value if the intuitiveness and ease of perception of the offered data are not assured. Therefore, visualization has a central role that determines the effectiveness of offered information such as the level of assessed knowledge and skills, or the difficulties/misconceptions encountered by the user [66]. Basically, all types of learner models can be opened to users, and the reason for this access will determine the technique of illustrating the model. Moreover, model data visualization depends on who will access these data (educators, parents, or peers) in combination with the purpose for using the information (i.e., context and tasks) [67].

5. OLM Visualization Options

OLMs are able to take over the responsibility for presenting learner model data in an understandable form, to allow for appropriate actions and decision making. Usually, internal learner model mechanisms and inference logic are too complicated to be presented to learners, peers, teachers, or parents without being processed or filtered; therefore, the simplification of learner model data is necessary through visual presentation [67]. Due to the many different usages and potential users accessing the model, various visualizations could be deployed to serve adequately the OLM purposes [68]. OLM visualizations may include data about the learner, data that compare the learner with peers (individuals or a group, e.g., best scoring classmates), data about other individual learner(s), or the average/summative performance of a complete class. A search in the related literature identifies a variety of available visualizations, namely:

- Bar Charts and Histograms usually represent learner performance, competencies level, and activity level (posts to forums, access frequency, content view durations, etc.).
- Pie Charts in OLMs are used similarly to bar charts, but they have limitations concerning the number of values and do not support detailed comparisons [69,70].
- Radar Plots [71] support easy comparisons and identification of outliers. A radar plot can be used to represent multiple learners and compare them on various dimensions (e.g., performance, activity level, topics covered), or it can also depict a single user.
- Scatterplots [72] can represent either a single learner (performance, activity level, topics covered, etc.) or compare multiple learners using different colors or point shapes.
- Tables are used to represent either a single learner (performance, activity level, topics covered, etc.) or multiple learners (each one in a different row or column).
- Timelines can depict information arranged on a time scale and convey trends (e.g., learner progress, learner access history) [73–75].
- Network Diagrams [70,71,76] are used to represent learner associations (learners are nodes and associations are edges) or content associations along with learner performance (topics are nodes and the way nodes are coded in color/size/shape denotes learner performance on each topic). When clicking on a node of the network, it may be expanded or collapsed to present more or less information [77].
- Tag/Word Clouds [70,76,78] present the level of competencies or weaknesses and can distinguish their respective degree (level).
- Skill Meters represent a simple overview of the learner model contents, which are typically found as a group of more than one skill meters assigned to each topic or concept. In addition, separate skill meters could be used for sub-topics allowing a simpler structure of the model presentation [79]. Most skill meters [71,76,80] display the learner level of knowledge, understanding, or skill compared to a subset of expert knowledge [79,81] in the form of proportion of the meter filled [76,82].
- Sunbursts are multi-level pie charts, which visualize hierarchical data, depicted by concentric circles [83]. The circle in the center represents the root node, with the hierarchy moving outward from the center. A segment of the inner circle bears a hierarchical relationship to those segments of the outer circle that lie within the angular sweep of the parent segment [84]. In OLMs, sunburst charts can present the complete learner model in concentric sectors. In some implementations, sunbursts are interactive, and the user can get more information describing the sources that support the current values, or the learner can access other sections related to a specific concept [85].
- Concept Maps depict ideas and information (concepts) as boxes or circles that are connected with labeled arrows in a downward-branching hierarchical structure [86,87]. Concept maps [78] can be pre-structured to reflect the domain, with the nodes indicating the strength of knowledge or understanding of a concept [88].
- Bullet Charts can be interactive and provide details concerning the way individual scores are calculated, and learners can view the tasks that contribute to a specific learning outcome and identify tasks that can improve their level. Bullet charts are typically unstructured OLM visualizations.

- (Hierarchical) Trees are typically used for depicting learning concepts and their structural relations along with annotations that refer to the current learner competencies [85,87,89,90].
- Treemaps depicts hierarchies in which the rectangular screen space is divided into regions, which are also divided again for each level in the hierarchy [91]. Through size, there is an indication of topics' strength, and typically, a learner can click on a cell to view the next layer in the hierarchical structure [77].
- Gauges depict learner skills on specific topics and can also integrate a scalar set of values representing discrete ranges, as in [64]. Each gauge represents a specific learner.
- Grids use color to indicate level of understanding [92] on a specific topic. They may display a single learner or multiple learners as in MasteryGrids [61] that use cells of different color saturation to show knowledge progress of the target student, reference group, and other students over multiple kinds of educational content organized by topics. Grids are unstructured OLM visualizations.
- Burn Down Charts graphically represent the remaining work versus time. In OLMs, through burn down charts, learners can track their own progress, showing target and projected completion time, percentage of assignments submitted and completed [66]. Thus, they are self-assessment tools keeping learners motivated and focused on their objectives.
- Task lists and focus lists (tasks to be focused on to stay on track) support student engagement with frequent formative feedback. The task list uses different colors in order to keep learners informed about the status of their task [66].

Visualization plays a crucial role in representing data from a learner model, as the appropriate match between data and type of visualization would result in users' better apprehension of the information. According to Bull and Kay [67], it is important to go through a phase simplification on learner model data when deciding the form of visualization being used for pupils, teachers, and parents, omitting complex details such as user monitoring details, inference logic deployed by the adaptation mechanism, etc. Different ways of visualization are recommended for different viewer roles, as different information is necessary in each case and should serve different purposes and user tasks [68]. When visually representing data, variations in fill, color position, and/or size can indicate differences in level of understanding, competencies, skills, and curricula coverage [92]. Most typical visualization types are bar charts, pie charts, radar plots, scatterplots, tables, timelines, network diagrams, and skill meters [93]. There are OLM-based systems that support multiple representations, as research has supported that users enjoy having control over the choice of visualization type, although some visualizations are more preferable [87,94,95].

When visualizing learner models in digital educational games, simple quantized representations are recommended, such as target–arrow, where the number of arrows depicts the level of knowledge for the specific topic (typically up to four levels) [64,96], smilies (smiley faces), where a smiley (or not) face with scalar variations represents knowledge level or contrast a learner's level with the level of peers [97], stars, where the number of stars presented or filled with color (from a fixed number of total stars typically 4–5) depicts learner skill level [77], liquid in a cup or container, where the amount of filled liquid depicts learner's skill level [81], growth of tree, where the different growth stages of the tree depict the different skill levels of a learner [98], and more.

For OSLMs, user model visualizations are selected on the basis of how well they can show social comparison (two individuals, one individual and a group, etc.) [60,61,92,99,100].

6. Multiplication Game Description

The MG is a web-based practice and progress monitoring game that serves educational and scientific purposes. It started out as an adaptive mobile application (v.1) [101], and it was extended as a desktop application with incorporated OLM elements (v.2) [102]. Followingly, it was revised by adding social characteristics to the OLM, as the learner model is now open apart from the learner, also to teachers and peers (v.3) [103]. The design and implementation of the MG is based on the belief that multiplication tables fluency is a very significant skill; therefore, it should be supported by engaging and motivational assessment tool. Since in this paper, the focus is placed on teacher support aspects, the game play is briefly described to provide an overview picture of the game, while the functionalities that are offered to teachers are presented in more detail.

6.1. Brief Description of MG

After the player logs into the game, (s)he can choose which number(s) to practice. The player goes through four levels with different types of questions in each one: (a) right or wrong, (b) multiple choice, (c) matching question with result, and (d) fill in the blank. With the completion of each level, the player can be informed about their own progress. Furthermore, the MG incorporates an adaptive algorithm that undertakes to make a diagnosis (after completing each level) of the player's main weakness and tries to "treat" this difficulty by supporting the player on this particular number in the next level. Upon the game finishing, the player has the option to access the overall progress in the specific game as well as compare the overall progress of the three most recent games. Student can also compare own progress with the average progress of their classmates and see the 5 high scorers in the class.

6.2. Description of MG's Teacher Daskboard

The MG offers teachers insight into their pupils' multiplication skills (progress/evaluation and history). By using the MG, a teacher can be discharged from the time-consuming correction of pupils' schoolwork on paper (or significantly reduce this effort) using instead the detailed data and progress record of each student maintained by the MG. Depending on teacher's selections, the MG collects selected data from the respective learner model (in the case of an individual student) or from multiple learner models (in the case of all the classmates), and they are presented in an adequate graphical form [104]. As already mentioned, visualization enables comprehension and communication [105], and it depicts a much clearer image for the human brain compared to words or numbers [106]. In this approach, data are presented mainly in the form of tables and barcharts [107]. The information presented via the dashboard is selected according to the criteria of supporting teachers to easily access and assess their pupils, self-assessing their teaching practice outcomes, expose common mistakes of the particular student group, identify low achievers (in order to be more supported) and also help to (re-)arrange teaching process in the special needs of the pupil group (based on the feedback by the above visualizations).

Through the MG dashboard, the teacher can monitor the progress of the pupils—the progress of each individual student either overall or for a selected training number—and keep track of the student's game dates, the selected numbers for each game, the overall success rate and mistakes, as well as the frequency of each mistake. Figure 1 depicts a dashboard instance where the teacher chose to see the overall activity of student named "Ζωή N.".

Figure 1. Individual student progress.

When selecting a specific number, the teacher can see on a bar chart the student's success rates in each type of question (different game level). In Figure 2 for instance, number 4 was selected for tracking the activity of the student named «Αιμιλία Φ.».

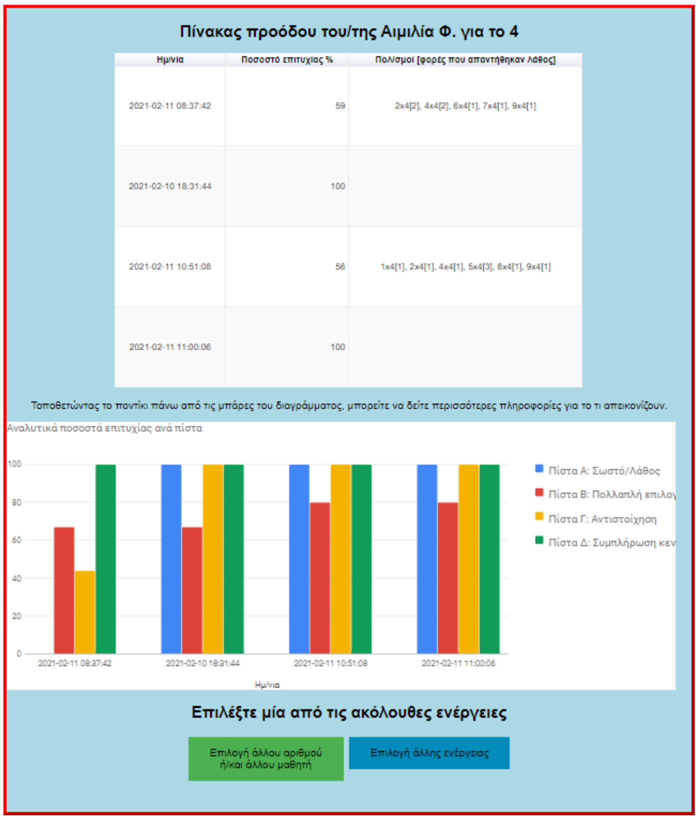

Figure 2. Individual student progress for a selected number.

In addition, the teacher can monitor the activity of all students on a specific date or time period (Figure 3).

Figure 3. Class progress on a selected date.

After selecting a specific date or a period of time (e.g., month), the teacher can see the students that played the game (Figure 4), their success rate for each number, and the summative success of all students on this particular multiplication number.

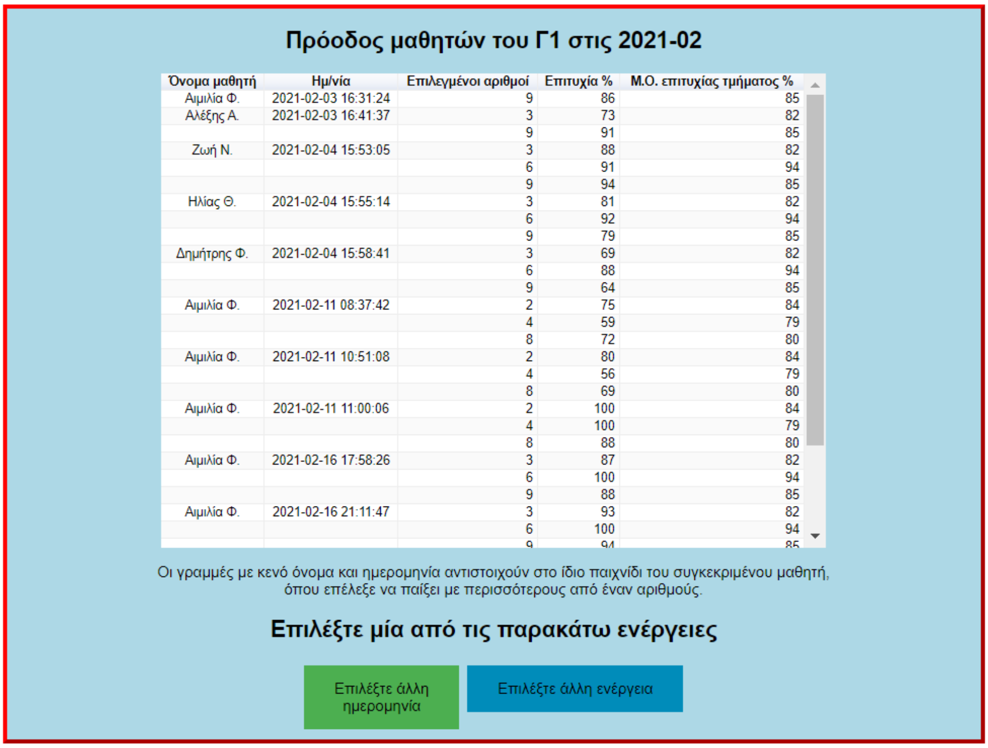

Figure 4. Class progress on a selected month.

7. Survey Methodology and Analysis

In the current study, we examined how this approach (i.e., the implemented MG and the dashboard recently incorporated) could facilitate the learning and teaching of multiplication skills. To reach teachers, a call for participation was sent through the official e-mail lists of primary schools. The 182 teachers that took part in the survey used the game (both the student view and the teacher dashboard) and were asked to fill in an anonymous online questionnaire with 37 questions and an optional comments field for general remarks about the game.

For the student view of the game, teachers were simply asked to play the game two to three times, make intentionally some mistakes, observe the score, see their progress per level, and see the progress of other students at the end of each game. For the teacher view, teachers were encouraged to explore the dashboard by connecting to a virtual test class with pre-assigned test students and readily available progress data. For additional support and to make sure that the teachers will try all major functionalities, a set of optional tasks were also provided: (1) See the progress record of student "Zoe N." for all multiplication tables she has selected. How many times did she answer 4×6 wrong? (2) Access the success rates for student "Aimilia F." for the multiplication table of number 4. Is 9×4 a multiplication she has answered wrong more than 3 times? Which type of questions seem to trouble her more?, and (3) See the activities of all your students on a specific date (4/2/21). Compare the score of student "Zoe N." with the average class score for the multiplication table of number 6.

This survey was conducted in order to investigate potential correlation between teachers' acceptance and positive attitude toward the notion of DGBL and their acceptance and perception about MG. Furthermore, it is very significant to have educators' opinion on the innovations MG shares with teachers, as they are given access to a dashboard that reveals detailed and summative aspects of their pupils' progress. More analytically, the purposes of the study included the following:

(a) To assess teachers' perceptions about MG's usefulness (MGU) in terms of perception/attitudes toward using digital games (ADG)
(b) To assess teacher's acceptance of MG (TA) and MG's usefulness (MGU) among to gender, age, and teaching experience
(c) To assess teacher's acceptance of MG (TA) in terms of barriers in using digital games (BD)
(d) To examine teacher's acceptance of using MG (TA) in the classroom in terms of teachers' attitude toward digital games (ADG)
(e) To investigate teachers' beliefs about the usefulness of MG in general (MGU)
(f) To investigate teachers' opinion about MG's interface (I)
(g) To investigate teachers' opinion about the OSLM characteristics of MG.

7.1. Method

7.1.1. Hypothesis Testing

Hypothesis 1 (H1). *Teacher's perception about MG's usefulness (MGU) is related to attitudes toward using digital games (ADG).*

Hypothesis 2 (H2). *Teacher's acceptance of MG (TA) and MG's usefulness (MGU) is related to gender, age, and teaching experience.*

Hypothesis 3 (H3). *Teacher's acceptance of using MG (TA) is related to perceived barriers in using digital games (BD).*

Hypothesis 4 (H4). *Teacher's acceptance of using MG (TA) is related to teacher's attitude toward digital games (ADG).*

More specifically, in order to examine teachers' beliefs about MG usefulness (MGU), two statements were given to be assessed on a 6-point Likert scale regarding how they consider the opportunity for students benefit in multiplication tables fluency when using MG, and MG's potential to support the traditional teaching process. Teachers' acceptance of MG (TA) was tested by asking them to assess on a 6-point Likert scale the likelihood of using MG systematically in their classroom and their intention of recommending MG to their students to use during their free time.

To examine teachers' attitude toward digital games (ADG), eleven statements were given to be assessed on a 6-point Likert scale regarding teachers' own attitude toward digital educational games, their own opinion on the usefulness of digital educational games in the teaching process, whether digital games can have a firm place in the educational practice, and if digital games are a strong current trend in education (and they expect that they will be used more widely in the near future). Regarding teachers' opinion on barriers (BD), statements with five significant barriers identified in the related literature (i.e., lack of time, technical problems, lack of educational curriculum flexibility, and lack of information about suitable and available digital games) were assessed in terms of their perceived significancy on a 6-point Likert scale.

7.1.2. Research Participants

The sample used in this research included primary education teachers in Greece from the general public education. Responses for analysis were collected by distributing the questionnaire online. Hence, we gathered a total of 182 responses.

7.1.3. Design of the Instrument

The questionnaire used in this study was composed of three sections. The first section records the demographics of participants including gender, age, teaching experience, and teacher's frequency of playing privately digital games. The second section refers to teachers' attitudes toward digital tools in their teaching, and the third section concerns MG's usefulness. The assessment tool contained 6 factors and 37 questions. Within them, factors represented by questions were created, aiming to assess the teachers' attitudes. Each subscale comprised 2–11 items. The score of each item ranged from 1 to 6 based on a 6-point Likert scale design. The last question (38th) was an optional open-ended one where respondents could fill in in free-form text any comment they had concerning MG.

7.1.4. Methodology

Cronbach's alpha was calculated to determine the instrument's internal consistency. As concerns hypothesis testing, mean scores for MGU, ADG, TA, and BD were used to establish association between the study variables. Comparisons of means of the construct's distribution TA and MGU was desired for gender, age, and experience groups. Due to the non-normality of the variables' nonparametric tests, Mann–Whitney test and Kruskal–Wallis test were carried out. Spearman's rho identified the associations between the teacher's acceptance of MG (TA) scores and teachers' attitude toward digital games (ADG), the teacher's acceptance of MG (TA) scores and barriers in using digital games (BD), as well as MG's usefulness (MGU) and attitudes toward using digital games (ADG).

7.1.5. Data Analysis

Out of 182 teachers, 159 (76.8%) were female, with the majority (96, 46.4%) in the age group of 30–45 years. The mean of teaching experience of the study was 15.4 $\pm$ 9.4 years. A total of 113 teachers (54.6%) work in urban schools, with 69 (34%) working in a provincial area (Figure 5 and Table 1).

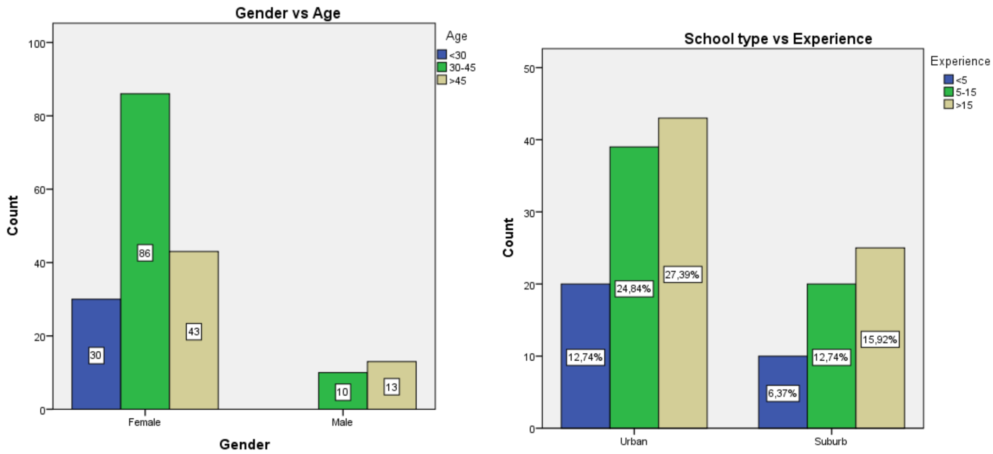

Figure 5. Demographics charts.

Table 1. Demographics of data.

Variables	N (%)
Gender	
Male	23 (11.1)
Female	159 (76.8)
Age	
<30	30 (14.5)
30–45	96 (46.4)
>45	56 (27.1)
Teaching Experience in years	
<5	34 (16.4)
5–15	67 (32.4)
>15	81 (39.1)
Teacher's playing hours	
>2 and ≥5	28 (13.5)
0	57 (27.5)
>0 and ≤2	89 (43)
>5	8 (3.9)
School area	
Urban	113 (54.6%)
Provincial	69 (33.3%)

Table 2 displays the mean scores for the key constructs, which are Teacher's attitude (perception) toward digital games (ADG)—3.97(0.672), Teacher perception about MG's usefulness (MGU)—5.32(0.78), Teachers' acceptance of MG (TA)—5.16(0.927), Barriers in digital games (BD)—4.52(1.066), Interface of MG (I)—5.10(0.759) and Social Opening of MG (SG)—5.07(0.890). Most of them present high mean scores (up to 5).

Table 2. Mean scores of variables.

Name of Variable (Acr.)	Min	Max	Mean Score	Std. Deviation
Teacher's attitude (perception) toward digital games (ADG)	2	5	3.97	0.672
Teacher perception about MG's usefulness (MGU)	2	6	5.32	0.784
Teachers' acceptance of MG (TA)	2	6	5.16	0.927
Barriers in d.g (BD)	2	6	4.52	1.066
Interface MG (I)	3	6	5.10	0.759
Social opening of MG (SG)	2	6	5.07	0.890

The constructs consist of several variables as depicted in Table 3, and a Cronbach test was used to assess their internal consistency. Cronbach's alpha values were higher than 0.7, which indicated the reliability of the proposed instrument.

Table 3. The construction of instrument.

Constructs-Items	Mean	Standard Deviation	Cronbach a
Barriers (BD)	4.52	1.066	0.764
V30	4.42	1.520	
V31	4.78	1.255	
V32	4.29	1.447	
V33	4.60	1.382	
V34	4.68	1.198	
MG Interface (I)	5.10	0.759	0.741
V36	5.04	0.891	
V37	5.15	0.879	
Social opening of MG (SG)	5.07	0.890	0.940
V39	5.02	1.022	
V40	5.02	1.040	
V41	4.98	1.005	
V42	5.14	0.935	
V43	5.18	0.947	
Teacher's Attitude (perception) toward digital games (ADG)	3.97	0.890	0.854
V14	4.94	0.953	
V15	5.03	0.895	
V16	5.15	0.937	
V17	2.71	1.291	
V19	4.55	1.250	
V21	3.92	1.336	
V22	4.96	1.179	
V23	4.63	1.158	
V24	3.68	1.468	
V25	4.19	1.249	
V26	4.08	1.311	
Teacher perception about MG's usefulness (MGU)	5.32	0.784	0.848
V34	5.27	0.814	
V35	5.38	0.869	
Teachers' acceptance of MG (TA)	5.16	0.927	0.828
V36	5.03	1.090	
V37	5.26	0.915	

7.1.6. Results of Hypothesis Testing

Spearman's rho correlation revealed that there is a significant correlation between MGU-ADG (r = 0.569, $p < 0.01$), TA-BD (r = 0.374, $p < 0.01$), and TA-ADG (r = 0.594, $p < 0.01$) (Table 4).

Table 4. Correlation between MGU, ADG, BD, and TA.

Variables (Hypothesis Testing)	Correlation Coefficient	** *p*-Value
MGU-ADG (H1)	0.569	0.0001
TA-BD (H3)	0.374	0.0001
TA-ADG (H4)	0.594	0.0001

** Correlation is significant at the 0.01 level (two-tailed).

As concerns H2 (Hypothesis 2), a Kruskal–Wallis test was conducted to examine the differences on TA and MGU according to the age groups and experience groups. No significant differences on TA (χ^2 = 1.907, p = 0.385, df = 2) and MGU (χ^2 = 2.656, p = 0.265, df = 2) were found among the three categories of age. Additionally, no significant differences on TA ($\chi^2 = 0.432$, $p = 0.806$, df = 2) and MGU ($\chi^2 = 0.263$, $p = 0.877$, df = 2) were found among the three categories of experience.

In addition, the Mann–Whitney U test showed that the distribution of TA (U = 1.454, $p = 0.1$) and MGU (U = 1.632, $p = 0.382$) is the same across categories of gender.

8. Discussion

This game of multiplication offers teachers the possibility to monitor the progress of their pupils. Specifically, the teacher can follow the progress of an individual pupil either for the overall activity or for a selected number. Through a properly configured dashboard, the teacher can keep track of pupil playing dates, the overall success rate, and the wrong multiplications as well as the frequency of each mistake. In the case of selecting a specific number, the teacher can see through the bar chart the student's success rates in each type of questions (which correspond to a different level in the game). Finally, the teacher can monitor the activity of all students on a specific date or time period (month). On a properly configured chart, the teacher can see which students were active at that time, each student's success rate on a training number (multiplication table), and the average success rate of all pupils in the classroom for a given number. The main purpose of this research was to investigate teachers' perception toward the MG in general and in relation to their attitude toward digital games. It was very important to find out teachers' willingness to use our tool and understand which are considered the main barriers that will possibly discourage them from utilizing the MG in their teaching process, as well as to reflect on their reactions regarding the social opening of the learner model supported by the MG.

According to the analysis of collected data in the previous section, the majority of respondents stated that it is very likely that they will use MG in the classroom and will recommend it to their students to use it at home as well, while they had a very positive opinion regarding the usefulness of the MG. More specifically, teachers stated that they strongly believe their students can benefit from using the MG and that it can significantly support them in their teaching.

Teachers rated positively the game interface usability and child-friendliness. The social opening of learner data to teachers was also assessed positively, as it allows them to plan more efficiently their teaching, making the appropriate adaptations to respond to individual pupil needs. Moreover, the fact that teachers can see the specific mistakes and their frequencies is considered as a very important feedback for improving their pupils' skills. Teachers also appreciated access to information about a pupil's progress on a selected number and the bar chart display of a pupil's progress in each game level (which reflects pupil scores for different question types in successive game plays).

Further statistical analysis revealed that teachers' positive attitude (perception) toward digital games leads to highly positive perception of MG's usefulness and to acceptance of the MG (H1 and H4). Furthermore, it was demonstrated that despite the severity teachers assign to barriers against using digital games, they are not becoming less willing to use MG in the classroom (H3). Finally, it is quite encouraging that teachers regardless of their gender, age, and teaching experience accept MG's educational value and usefulness (H2).

There were some quite interesting remarks made by teachers in the comments field of the questionnaire. Indicatively, there were remarks that a game such as the MG could greatly help students with attention deficit and other disorders, and that the game can help teachers save a lot of time they would typically spend examining each student in the classroom. In addition, some teachers stated that even though it is very important for the teacher to see details about the progress of each student, it is necessary to verify that it is the student alone that plays the game, and this cannot be guaranteed during off-school hours. This is a realistic issue and a limitation of the approach that can only be tackled if pupils play the game only at school, but this limits the opportunities for pupils to practice and improve their skills. It is a trade-off left to the teacher to decide and cannot be resolved by the game and the way it is implemented. In fact, it is a limitation faced by almost all remotely executed applications.

Another observation was that comparing the last pupil score with previous ones is a helpful indication of personal progress, but the social comparison (seeing the class average and the top scoring pupils) is not necessary and may discourage low-achieving pupils. Social comparison can be considered as a competition increase factor, which in turn is recognized as a strong motivation for improvement in educational settings [48,65,108–110]. The degree of competition and the details of implementing such features in the digital domain is a controversial subject. Our planned large-scale experiments with pupils will hopefully provide more insight on the topic from the pupils' standpoint.

Based on the feedback received by teachers and the analysis of collected data, teachers have positive views toward this approach for teaching multiplication and consider MG a useful learning tool from different points of view. Thus, there is strong evidence that MG could effectively support teaching and learning multiplication facts. This argument though needs to be verified and supported by large-scale experiments of the game with students and their teachers in the real-life setting of primary schools, which will be the next step of this effort.

9. Conclusions

The MG is a web-based assessment tool that supports pupils in acquiring and establishing multiplication facts skills. In the MG, learning and teaching goals are met, as it not only provides an engaging and motivating environment for pupils to play but also maintains a record of their activities in order to adapt to individual learner needs, to offer social comparison with peers, and to support informed decision making by the teachers. This paper describes the functional options offered to teachers by the MG dashboard and documents the outcomes of an online survey conducted with the participation of 182 primary school teachers. The purpose of the survey was to investigate teachers' attitude toward the benefits and support MG can provide to their teaching. To this end, the survey also recorded teachers' opinion on DGBL in general to allow for investigating potential correlation with their attitude toward MG.

According to existing bibliography [32,34,111], factors such as gender, age, and teaching experience influence teachers' beliefs about digital games. In our study, we found no evidence of gender, age, or teaching experience effect on teacher's acceptance of MG and their opinion about MG's usefulness. In addition, related bibliography [29,32,34,38,41,47,49,50,52] has identified many barriers that distract teachers from using digital games in the classroom. Evidence from the current study suggests that although teachers acknowledge the seriousness of four identified barriers, they did not affect their acceptance of MG. According to other researchers, factors such as the degree of relevance a digital game has to the educational context [34,41,44,51], its usefulness, and the learning opportunities it offers [37] can lead to adapting it in the educational process. Since MG satisfies these factors, it was expected and proved by the survey that MG is positively perceived by teachers. Furthermore, features such as students' support in knowledge acquisition [38,42,44,45,48], students' progress visualization [48], student rewarding, and entertainment [37] lead to the positive perception of a digital game. MG also possesses such characteristics, which contribute to its usefulness as perceived by teachers and their intention of using it.

The findings offer a promising basis for further exploration of the integration of game-based approaches to multiplication learning to promote active participation and interaction. These findings will be further investigated by planned extended studies that will involve a larger sample of participants comprising both teachers and pupils to lead to observations of learning effects and comparative analysis. As a next step, MG will be used a learning tool through several activities to study its effectiveness in the classroom with the participation of an adequately large number of pupils per grade of interest (second to fourth). The comparative testing of different MG versions (adaptive game, adaptive game with OLM features and adaptive game with OLM and OSLM features) is expected to reveal interesting findings in terms of learning outcomes, meta-cognition and motivation, and thus support teachers' positive opinion regarding the educational value of the MG as recorded in the presented study.

Author Contributions: Conceptualization, A.L. and M.R.; methodology, A.L.; software, A.L.; validation, A.L. and A.P.; evaluation of MG, A.L.; writing—original draft preparation, A.L.; writing—review and editing, M.R.; supervision, M.R. and J.G.; funding acquisition, A.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Hellenic Foundation for Research and Innovation (HFRI) under the HFRI PhD Fellowship grant number 267.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The questionnaire used for the survey is available (in Greek) at https://docs.google.com/forms/d/e/1FAIpQLSd3gYoK_c7wjGWz6j_K0lPWGKqOnVP36MGl7mt6cf5Zfsdamg/viewform?vc=0&c=0&w=1&flr=0&usp=mail_form_link (accessed on 18 March 2021) and the survey collected data can be acquired from https://docs.google.com/spreadsheets/d/1mS8nqKVW_2SuS617FDftxKStescnQuGTUcmS02sHFTM/edit?usp=sharing (accessed on 15 May 2021).

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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Article

A VR-Enhanced Rollover Car Simulator and Edutainment Application for Increasing Seat Belt Use Awareness

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Abstract: Most countries have active road safety policies that seek the objective of reducing deaths in traffic accidents. One of the main factors in this regard is the awareness of the safety measures, one of the most important being the correct usage of the seat belt, a device that is known to save thousands of lives every year. The presented work shows a VR-enhanced edutainment application designed to increase awareness on the use of seat belts. For this goal, a motorized rollover system was developed that, synchronized with a VR application (shown in a head-mounted display for each user inside a real car), rolls over this car with up to four passengers inside. This way, users feel the sensations of a real overturn and therefore they realize the consequences and the results of not wearing a seat belt. The system was tested for a month in the context of a road safety exhibition in Dammam, Saudi Arabia, one of the leading countries in car accidents per capita. More than 500 users tested and assessed the usefulness of the system. We measured, before and after the rollover experience, the perception of risk of not using the seat belt. Results show that awareness regarding the use of seat belts increases very significantly after using the presented edutainment tool.

Keywords: edutainment; serious game; gamification; virtual reality; traffic safety; rollover simulator; seat belt; awareness

Citation: Riera, J.V.; Casas, S.; Alonso, F.; Fernández, M. A VR-Enhanced Rollover Car Simulator and Edutainment Application for Increasing Seat Belt Use Awareness. *Computers* **2021**, *10*, 55. https://doi.org/10.3390/computers10050055

Academic Editors: Carlos Vaz de Carvalho, Antonio Coelho and Paolo Bellavista

Received: 3 March 2021
Accepted: 16 April 2021
Published: 21 April 2021

1. Introduction

The three-point seat belt was invented by Nils Ivar Bohlin, a Swedish Volvo mechanical engineer, in 1959. Prior to that date, some cars included passenger retention systems, but not as we know them today. It was recently the 60th anniversary of the invention of the seat belt and Volvo claims that its invention has saved more than one million lives [1]. Studies on the matter, such as the one presented in [2], assume that the seat belt has an effectiveness of around 45% (best estimate) in saving a person's life in a car accident.

The most advanced countries have included, in their legislations, the mandatory use of seat belts, both front and rear seat belts. Despite the legislation, seat belt usage rates are very different, depending on the country. In 2003, the European Union reported that, in its member states, only 76% of front seat occupants and 46% of rear seat occupants used seat belts [3]. In Australia, however, set belt wearing rates are much higher (95% in 2004) [4].

Since the use of seat belts became mandatory, it has become common for countries to develop campaigns that aim to increase the rate of seat belt use. Technical solutions have also been implemented in order to enforce its use. One of the first attempts in this regard was carried out by the United States of America, which in 1973 introduced in its legislation that cars should not be allowed to start unless seat belts were fastened. However, the measure was met with strong public opposition and was withdrawn only six months later.

Current techniques to encourage seat belt usage include smart seat belt reminders (SBRs) in cars; these systems trigger warning lights or sounds to remind passengers to buckle up their seat belts. This technique is quite successful, as reported in [5], where 82.3%

of car users without SBRs were reported to use seat belts; this number increased to 98.9% in cars with SBRs. In addition, car drivers with mild reminders used seat belts 93% of the time.

Technological evolution has also brought about new methods to develop campaigns with the objective to increase awareness on seat belt usage (with aims to achieve 100% usage). In this regard, serious games and educational entertainment (*edutainment*) applications have become very effective tools at raising awareness in various areas, not just for road safety [6]. Serious games are frequently used for educational, training, and health purposes, but are especially useful at increasing social awareness [7]. These are the so-called "games for good" that are characterized by addressing public, relevant social issues, such as epidemics, sexism and racism, climate change, etc.

This article presents an edutainment system developed by the Institute of Robotics and Information and Communication Technologies of the University of Valencia (IRTIC-UV), within the framework of a road safety campaign in Dammam, Saudi Arabia, to help increase awareness on seat belt usage. Saudi Arabia is one of the leading countries in traffic accidents per capita, with one traffic accident every minute, causing up to 7000 deaths and over 39,000 injuries annually [8]. In fact, the use of the front passenger seat belt only became mandatory in December 2000 in Saudi Arabia [9]. Thus, these kinds of campaigns are very important, since social awareness regarding the use of seat belts is rather low [10].

The developed system includes a virtual reality (VR)-enhanced rollover car simulator, where each of the car's four passengers has a different view, provided by a head-mounted display (HMD). The objective is to show how a virtual car experiences an accident and overturns, while the real car, where the passengers are mounted, turns around driven by a powerful motor synchronized with the VR scene. Although the application has a playful appearance, and the virtual scene is setup as an entertainment car simulator, the rollover simulator gives car occupants the unpleasant sensation of being in an overturned vehicle. This is expected to cause that users immediately understand that wearing a seat belt is a serious matter, increasing their awareness in the use of the seat belt, which is the objective of the application. In fact, our initial hypothesis was that the use of the rollover car simulator and edutainment application would provide a significant increase in seat belt use awareness. This hypothesis is confirmed by the datasets collected with the use of the application.

The rest of the paper is organized as follows. Section 2 reviews the related work. Section 3 describes both the design and the system's architecture. Section 4 describes and discusses the experiments and their results. Finally, Section 5 draws the conclusions and outlines future improvements.

2. Related Work

VR could be defined as "the process, means and technologies by which one or several individuals experience the sensation of belonging to an alternative reality that is not the one they are actually living in" [11]. Although this alternative synthetic reality needs to be believable enough so that it is accepted by the participants, accurate recreations of all the perceptual stimuli are still impossible. In fact, this is often undesirable because the simulated actions could be, in some occasions, harmful. Thus, it is acceptable that the perception of belonging to the virtual world be only partial. The simulation of accidents is a perfect example of this situation.

A simulator is a system (it does not need to be computer-based!) that replicates a process, natural phenomenon, or experience. Simulators often use computers to solve internal models and/or provide visual outputs, but there are also simulators in which no visual output—or computers—are strictly necessary. Rollover simulators are an example of this. A rollover simulator is an engineering application in which the cab of a vehicle—or even a complete vehicle—is mounted on top of a motorized encasement/structure. The motor rolls over the vehicle, simulating a rollover accident [12].

There are many types of VR applications, including of course, entertainment, educational applications, and serious games. These applications can also be provided with other visualization and interaction paradigms, such as mixed reality (MR), augmented reality (AR), etc. Although many VR applications and simulators are designed as games, they do not have to be games. Thus, it is important not to confuse these terms.

There are many definitions of *edutainment*, but one of the most accepted is provided by Corona in several of his works [13,14]. He defines it as "the combination of education and entertainment in a learning process". Makarius [15] states in her work that "the process of educating in an entertaining way has been greatly facilitated for educators thanks to new technologies". Buckingham and Scanlon [16] state that "edutainment is based on attracting and maintaining the attention of students through the use of displays or animations to ensure that learning is fun". In fact, it has been shown that, thanks to the use of these new technologies, which usually include various stimuli (e.g., images, sounds, or videos), students are more likely to pay attention to the content, transferring it from their short-term memories to their long-term memories [17]; thus, it essentially becomes knowledge to them.

There are many educators, in several areas, who are increasingly betting on the use of edutainment for the transfer of knowledge. Ma published a book [18] from which the close proximity between edutainment and the so-called *serious game* was extracted. A serious game (SG) is usually defined as "a computer-based game with a particular learning purpose" [19]. The term *gamification* refers to a slightly different concept. Gamification is the introduction of game-like mechanisms in learning applications, whereas a serious game is usually a full game with a learning purpose. As an example of the increase in the use of these educational systems, Zhonggen [20] analyzed the number of publications made between 2009 and 2019 related to serious game assisted education, using the search tool Web of Science. The results show that the number increased from about 20 publications in 2009 to more than 200 in 2017.

Aksakal [21] and Simon [22], in their works, include the concept of using edutainment for awareness. In this sense, serious games, gamification, and edutainment, have historically been used to raise awareness about good environmental practices, social behavior, cultural heritage, nutritional health, etc. [6,23–27]. Safety and health are two areas in which other types of IT-based applications can provided important benefits, using paradigms such as big data or artificial intelligence [28,29].

Focusing now on the use of serious games, gamification and edutainment to raise awareness about good driving practices, Riaz [30] conducted a study to evaluate the use of gamified e-learning to improve road safety in elementary school students. The study concluded—similarly to Klawe [31]—that strategies based on gamification are very positive for motivation in learning. Vera [32] developed a serious game based on a hybrid system with virtual reality and augmented reality, with the aim of raising awareness about road safety, concluding that the serious game was an effective tool to increase driving safety awareness, especially for younger people. This is good news for the future.

In a very recent publication, Gounaridou [33] proposed an SG in which a virtual character moves around a virtual city to complete a mission. The character needs to follow road safety rules as a pedestrian or as a vehicle driver. The results show that the SG could enhance road safety awareness and social responsibility. The use of the seat belt is not specifically targeted or analyzed. Other similar works [34–36] studied the use and benefits of using edutainment or SGs for traffic safety. It is generally accepted that gaming approaches can provide safe environments where users can practice and learn traffic rules and also recognize and manage dangerous situations [37].

However, the academic literature is very limited in relation to the use of these types of applications in raising awareness on seat belt usage. In aviation, Chittaro and Buttussi [38] evaluated the use of a serious game in relation to safety in airplane cabins, which included the use of seat belts. Although some road safety applications also include the use of seat belts in their learning goals, there is a lack of edutainment applications dedicated specifically to increase seat belt use awareness.

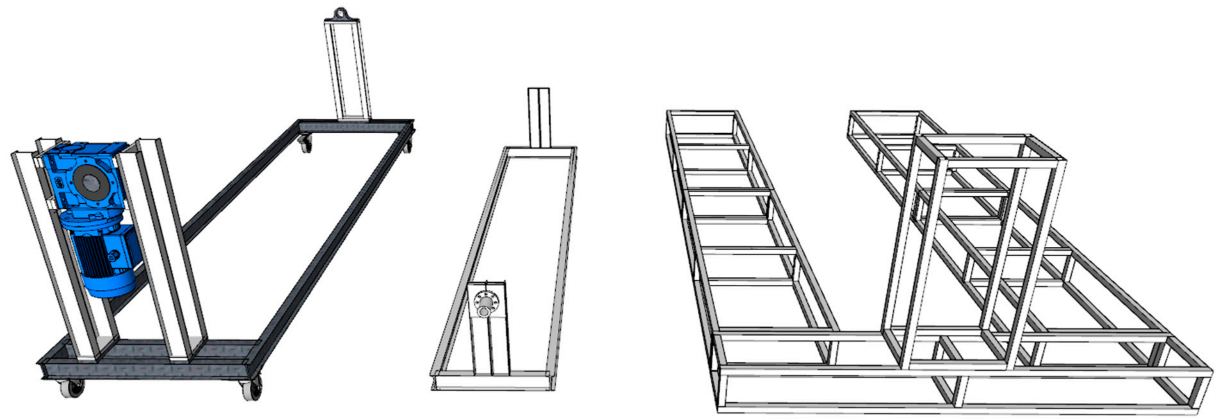
In regards to rollover simulators, several works exist in the academic literature where accidents are simulated, including simulated turnovers (i.e., simulated tests of rollover maneuvers), but no documented real rollover simulators (where a real car is physically turned upside down) have been found. Some rollover simulators can be found in the commercial field [12,39,40], but, to the best of our knowledge, no scholars have ever proposed an edutainment VR-based application synchronized with a rollover simulation, with the intention of being used to raise awareness on road safety. Thus, our proposal is innovative, original, and intends to target this research gap. The use of VR helps increase the immersion and presence of the system, complementing the rollover experience. Immersion and presence have an impact on memory [41]; therefore, it is expected that they help users remember the rollover experience, contributing to the fulfillment of the objectives of the proposed application.

3. System Design

This section describes the mechanical system, the simulation software, and the communication architecture between the different parts of the system.

3.1. Mechanical System

The rollover simulation system is based on a steel structure that is divided into three parts (see Figure 1). The first one (Figure 1a) is anchored to the ground and includes a powerful electrical motor, which will be used to roll the car over. The second part (Figure 1b) is supported by two large bearings. This is the moving (rotating) part of the system onto which the real car is placed and clamped. It is responsible for the generation of the motion cues of the simulator, although no motion cueing algorithm (MCA) [42,43] was needed in this application.



(**a**) (**b**) (**c**)

Figure 1. Hardware parts in which the main structure of the rollover simulator is divided; (**a**): supporting structure with the electrical motor (shown in blue color); (**b**): rotating structure onto which the real car is placed and clamped; (**c**): auxiliary structure to ease access to the car.

To convey a correct aesthetic appearance and facilitate the entry and exit of users to the car, the entire steel structure is surrounded by an aluminum structure (Figure 1c).

The moving part integrates the car's clamping mechanism. Specifically, this mechanism was designed to anchor a 2016 *Kia Picanto*. This car model has been selected based on its dimensions, weight, ease of access to the chassis fixing bolts, and because it is a mid-range utility vehicle. Thus, it perfectly exemplifies much of the existing vehicle market.

The moving part of the system is driven by a 1.5 kW electrical motor and a 1:750 gearbox (in fact, there were two gearboxes connected in series, making a 1:750 gearbox system).

To turn the moving part and the car with this electrical motor, very precise calculations were made to take into account the resulting center of mass with four users inside the vehicle and, thus, place the motor and the rotation axis in the optimal location.

The nominal angular speed of the engine is 1500 revolutions per minute (rpm). Thus, a 1:750 gearbox basically amplifies the output torque by a factor of 750, at the cost of reducing the output angular speed to a maximum of 1500/750 = 2 rpm. This means that it takes 30 s to turn the car completely (360°), and 15 s to turn the car upside down (180°). Of course, this is slower than the angular speed at which a real car overturns when it suffers an accident. However, for safety reasons, rotational speed should be kept slow in the simulator.

The motor is controlled by a frequency inverter using amplified analog signals provided by an Arduino Uno, which includes an Ethernet connection module that, through a router, allows commands to be sent using UDP sockets. In addition, for cases where manual control of the motor rotation is necessary, the Arduino Uno has a control system with two buttons (forwards and backwards), and an emergency stop pushbutton (mushroom-type button) connected directly to the motor break system. This way, the rollover car can be stopped immediately in case of emergency. The communication architecture will be described in Section 3.3, once the application is described in detail.

3.2. VR-Based Edutainment Application

To increase the immersion of the users, in addition to the actual rollover motion that they suffer thanks to the mechanical system, each person wears a VR HMD (VR glasses). Specifically, we used a Samsung Gear VR with an LG G4 smartphone inside. Given the high power consumption needed by the VR application, the smartphones remained always connected to the power supply. They were also numbered according to the seat they correspond to in the vehicle, since the visual perspective is different for each of the seats.

The VR application includes a recreation of the interior of a Kia Picanto, positioning the virtual camera according to the seat that each user occupies. A virtual road and landscape were also created, so that the virtual car is shown travelling through a two-lane road. The car is driven by an autopilot. Thus, the person in the driver's seat experiences the same sensations as the rest of the passengers.

At a certain random moment, the application produces a highly directional sound (suggesting a puncture or the breakage of a mechanical part) that causes confusion in the users. They usually stop looking forward and try to locate the source of the sound, as if it was a game of discovery. At this point, after a few seconds, the vehicle leaves the road, falls into an uneven sand embankment and overturns. As soon as the virtual vehicle leaves the road, the actual rollover of the car occurs. This is accomplished by synchronizing the virtual car with the electrical motor of the rollover simulator. Figure 2 shows a snapshot of the VR application.

When the (real) car has turned 180°, the electrical motor stops, thus holding the users for 15 s upside down (see Figure 3), so that they can experience through the VR-based edutainment application what happens to the objects in the car. In a real car, there are usually objects in the interior of the vehicle and they fall and cause injuries in the event of a rollover accident. VR is a safe way to simulate the fall of these objects without causing damage to users. Thus, all the virtual objects placed inside the vehicle interior (a pair of sunglasses, a pack of tissues, a soft drink, and a backpack) fall down. In addition, if the users have small objects in their (real) pockets, such as coins, tissues or candy, these objects usually fall down as well, increasing the perceived danger. Nevertheless, users are not allowed to test the rollover simulator with heavy or dangerous objects that can fall down and cause injuries.

After 15 s of holding the passengers upside down, the virtual simulation ends, and a command is sent to the Arduino Uno to turn the car another 180°. Therefore, the car returns to its original position, finishing the seat belt awareness experience.

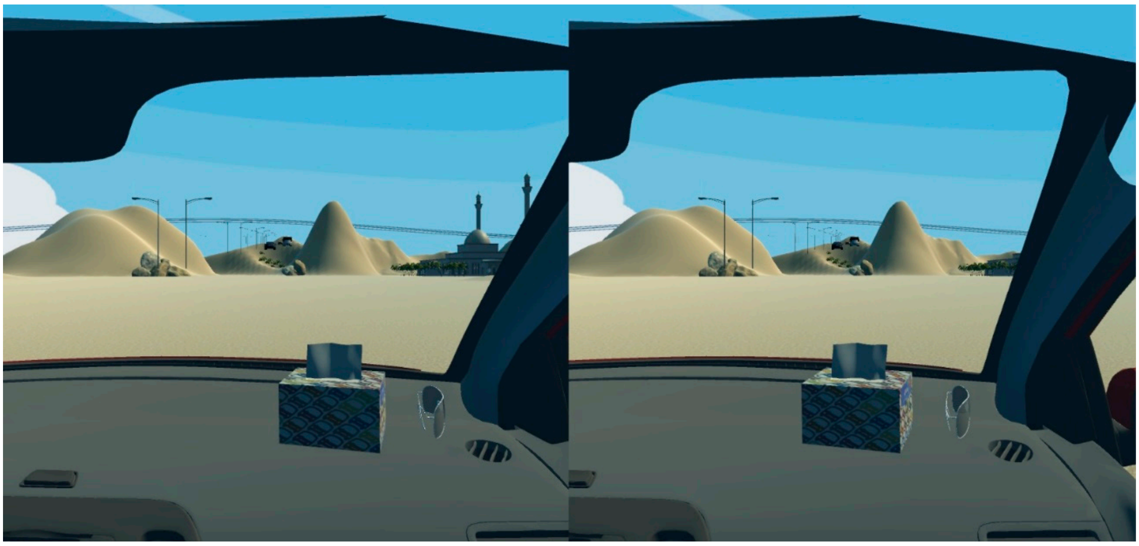


Figure 2. Snapshot of the simulation as seen from the front passenger's position. The two images correspond to the right and left eye, since the VR application is a stereoscopic software.

Figure 3. The rollover simulator with the car turned upside down (180° turn).

Even though the real motion cues generated by the rollover simulator provide an uncanny feeling, the application is setup with an edutainment perspective. The visuals of the VR application are created using a cartoon look (see Figure 2). In addition, the mascot of the road safety campaign, called Hakeem, is shown on the dashboard of the car (see Figure 4). Hakeem also falls down when the car turns over. This fictional character is used throughout the road safety campaign to provide advices and warnings about road safety. Mascots and virtual assistants are common in SGs and edutainment applications [44,45]. Their playful look is essential to engage the younger audience [46,47], which is very important in the case of road safety. For this reason, the use of mascots is also very common in marketing campaigns of products targeted for children [47].

Figure 4. Hakeem, the virtual mascot of the road safety campaign, appears in the VR application.

3.3. Communication Architecture

The communication between the mechanical system and the mobile phones showing the VR application is achieved through a router to which both the mobiles phones (via Wi-Fi) and the Arduino Uno (using the Arduino Ethernet shield) that controls the electrical motors, are connected. There is also a control tablet, used by a system operator, which is connected via Wi-Fi as well. This tablet controls the simulation, allowing starting and resetting the edutainment application. It also allows performing an emergency stop and the direct control of the rotation of the electrical motor. Figure 5 shows the communication architecture.

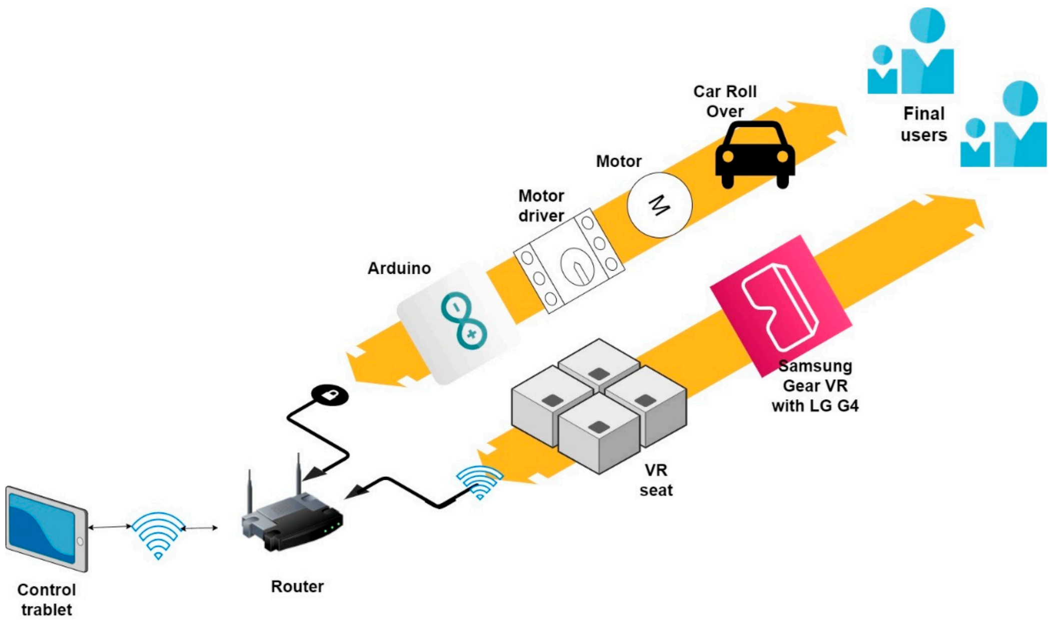


Figure 5. Communication architecture. The system is composed of a control tablet connected to a router via Wi-Fi, four mobile phones connected also to the router via Wi-Fi, an Arduino Uno connected to the router with an Ethernet cable, and an electrical motor controlled by the Arduino Uno through a motor driver. This motor rolls over the real car. The users wear Samsung Gear VR glasses, where the cell phones are inserted.

The control operator is the person who controls the rollover experience. Once the users are in the car and with the seat belt properly fastened, he/she launches the simulation. In the unlikely event that any person suffers any problem, he/she can immediately realize (since the operator has direct vision of the rollover car and its passengers), abort the simulation and bring the car back to the rest position.

4. Experiments and Results

The system was installed in a road safety awareness campaign in Dammam, Saudi Arabia, organized by the state oil company Saudi Aramco. This campaign was oriented and organized so that the drivers came with their whole family. Thus, both old and young people could increase their road safety awareness. Young people are essential, since they will become the main drivers in the next decade and are prone to accidents. This type of campaign is common in the Kingdom of Saudi Arabia (KSA) (e.g., [48]), given the high accident rate and annual driving fatalities that the country suffers [49].

The campaign was organized in a circuit of five edutainment activities, one of them being two rollover simulators, such as the one described above. This attraction was the only one of the five activities focused on raising awareness about the use of seat belts. Figure 6 shows the two rollover simulators installed. The other four IT-based activities prepared for the road safety campaign were an AR road safety game shown in [32], a 5D interactive theater ([50] shows a preliminary version), an AR application for vehicle maintenance tips, and an interactive e-game with tablets for theoretical and practical driving support.

Figure 6. Two rollover simulators installed inside the road safety campaign in Dammam, KSA.

When the families arrived at the venue, they were first registered at a welcome desk (see Figure 7). Then, they were required to fill out a questionnaire on one of the 10 tablets enabled for this purpose. Once registered, they were provided with a tracking code that they used during the various activities. They also used this code to fill out a second questionnaire before leaving the venue. Since both questionnaires, pre and post, are known to belong to the same person thanks to the generated code, it is easy to see the differences between the *before* (pre) questionnaire and the *after* (post) questionnaire.

(**a**) (**b**)

Figure 7. Register/welcome desk (**a**) and tablet used to fill out the questionnaires (**b**). The welcome desk was the entry and exit point of the campaign and users were prompted to fill the questionnaires upon entering and leaving the venue.

Table 1 shows the questions asked about the use of the seat belt before (pre) and after (post) going through the set of five activities. The complete questionnaire included other questions related to road safety. We only show in Table 1 the questions related to the seat belt. It is important to point out that none of the other four activities of the campaign was related to the seat belt. Therefore, it is expected that all the differences regarding awareness on the use of the seat belt be caused by the use of the presented VR-enhanced edutainment application.

Table 1. Pre (left) and post (right) questionnaires related to the use of the seat belt.

#	Questions Regarding Seat Belt (Pre)	Questions Regarding Seat Belt (Post)
A	When you get into the car as the driver, do you always wear your seat belt?	From now on, when you get into the car as the driver, will you always wear your seat belt?
B	When you get into the car in the passenger seat, do you always wear your seat belt?	From now on, when you get into the car in the passenger seat, will you always wear your seat belt?
C	When you get into the car in the back seats, do you always wear your seat belt?	From now on, when you get into the car in the back seats, will you always wear your seat belt?
D	Do you think that the seat belt helps save lives?	Do you think that the seat belt helps save lives?
E	Do you know someone who has saved his/her life thanks to the seat belt?	Do you think the seat belt could have saved the lives of someone you know?
F	Do you think it is important to wear a seat belt even if you are not the driver?	Do you think it is important to wear a seat belt even if you are not the driver?

The campaign ran for four weeks in a row, being open to the public six days a week. In total, more than 5000 people passed through this road safety venue—not counting those under 8 years of age, who did not answer the questionnaires—. However, of all the users who tested the VR-enhanced rollover simulator and answered the questionnaires, some of them did not fill them completely or did it in an inconsistent way. For instance, some users always chose the first or the last option shown to them. Others filled all the answers with “Yes” or “No” answers. Others provided contradictory answers for similar questions. Finally, some people did not fill either the pre or the post questionnaire correctly. Thus, those users for which it was clear that either of the questionnaires was not seriously answered were discarded. Finally, 561 pairs of questionnaires were considered consistent, the results of which can be seen in Table 2.

Table 2. Results of the questionnaires.

Question	Pre (Before)			Post (After)		
	Yes	No	% of Yes	Yes	No	% of Yes
A	323	238	57.58	524	37	93.40
B	286	275	50.98	522	39	93.05
C	130	431	23.17	486	75	86.63
D	351	210	62.57	546	15	97.33
E	29	532	5.17	149	412	26.56
F	298	263	53.12	520	41	92.69

As can be seen in the questionnaire, the desired answer for each of the questions was "Yes". As can be seen in Figure 8 and Table 2, in all of them a considerable increase in positive responses is observed when comparing the pre and post questionnaires.

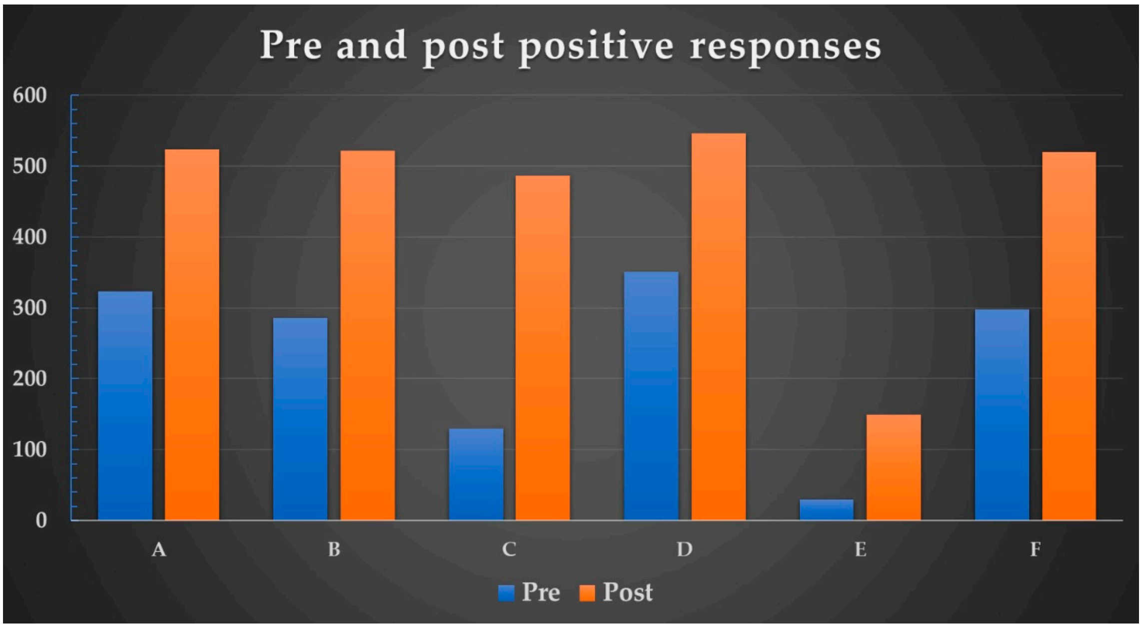


Figure 8. Pre and post responses in the questionnaire. Blue bars represent the amount of positive responses before the use of the application (pre). Red bars represent the amount of positive responses after the use of the application (post).

Regarding questions A, B, and C, which were very much oriented to the use of the seat belt in the different seats of the car, it should be noted that, initially, only 23.17% of users perceived that it was important to wear the seat belt in the rear seats of the vehicle. After using the rollover simulator and edutainment application, this figure increased to 86.63%. Despite the large increase in awareness, there is still a significant variation between awareness of seat belt use in the front and rear seats. In the post questionnaire, 93.40% (driver seat) and 93.05% (passenger seat) of the users perceived the use of the seat belt in the front seats as important, compared to the 86.63% already mentioned for the rear seats.

On the other hand, questions D and F reflect two important concepts: whether the use of the seat belt is considered important and whether or not its use depends on the seat in the car. These questions show an increase from 62.57% and 53.12% in the pre questionnaire to a 97.33% and 92.69%, respectively, in the post questionnaire. These are very significant increases. Given the large amount of answers obtained (N = 561), these increases are statistically significant.

5. Conclusions and Further Work

The use of the seat belt saves thousands of lives every year. For this reason, the presented work shows a VR-enhanced rollover and edutainment application designed to increase awareness on the use of the seat belt. The use of VR provides three important benefits in this context: (i) it allows simulating the fall of objects safely; (ii) it provides a way to control the visual output of the simulator and modulate its playful look; (iii) it provides context for the rollover simulator, making clear that a rollover is not just a fabricated experience and can happen quite easily in a car accident.

Our hypothesis is that the use of this edutainment application would provide a significant increase in seat belt use awareness. The system has been tested for a month in the context of a road safety exhibition. More than 500 users tested and assessed the usefulness of the system. We measured—before and after the rollover experience—the perception of risk of not using the seat belt.

From the results obtained, it can be seen that users had a very low initial awareness regarding the need to use seat belts in cars, especially in the rear seats. However, after the experience in the edutainment rollover simulator, it is observed that this awareness increased very significantly, not only in relation to the rear seats, but also to the use of the seat belt in general. Therefore, the presented edutainment application, combining VR, a playful look, and real motion, is able to fulfil its goals, as it provides a significant increase in the awareness of the use of the seat belt, showing the potential that these kinds of applications can offer, and confirming our research hypothesis.

It should be noted that this increase in awareness occurs after the use of a simulator that only rotates at 2 rpm, which is far from the angular velocity that users would feel in a real accident. Real accident accelerations and angular velocities are several orders of magnitude higher. Of course, we did not want to hurt anyone. Therefore, a slow motion system was implemented. Despite this apparently important limitation, the application is able to generate a significant impact on the users. Indeed, the feeling of being upside down trapped in a car that has overturned is as real as it can be in a real accident (blood and injuries aside). The authors have tried the simulator themselves, and although the rollover motion is fun at first, the feeling of being upside down in a car, even for a few seconds, is unpleasant. In that position, you realize that the seat belt can prevent you from hitting the interior of the car when you suffer an accident.

In the future, we intend to introduce interaction with users in the system, so that instead of being an autopilot simulation, the users themselves would drive the vehicle inside the VR system. Thus, if they lose control of the car and suffer an accident, the rollover simulator will provide the motion cues so that users feel how the car overturns. It is possible that this new setup will increase the concentration of the driver and, therefore, the surprise when losing control, further increasing awareness on the need to wear a seat belt. We also plan to test the system under different configurations (angular speed, duration, virtual content - including also the possibility of not using VR at all -, etc.), so that we can evaluate the influence of these factors in the increase of seat belt use awareness.

Author Contributions: Conceptualization, S.C. and F.A.; methodology, S.C. and F.A.; software, S.C. and J.V.R.; validation, J.V.R., F.A., and M.F.; formal analysis, F.A.; investigation, J.V.R. and M.F.; resources, J.V.R. and M.F.; data curation, J.V.R.; writing—original draft preparation, J.V.R.; writing—review and editing, J.V.R. and S.C.; visualization, J.V.R. and S.C.; supervision, F.A. and M.F.; project administration, M.F. and F.A.; funding acquisition, M.F. and F.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the R&D contract "Development Installation and Support of an Educational Road Safety Campaign in the Framework of the 'House of Knowledge' Campaigns in the Scope of the 'Traffic Safety Signature Program' of Saudi Aramco" between the University of Valencia and Sahara Consultancy.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: All subjects gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki.

Data Availability Statement: Data sharing not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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Article

iSTART StairStepper—Using Comprehension Strategy Training to Game the Test

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Abstract: Literacy skills are critical for future success, yet over 60% of high school seniors lack proficient reading skills according to standardized tests. The focus on high stakes, standardized test performance may lead educators to "teach-to-the-test" rather than supporting transferable comprehension strategies that students need. StairStepper can fill this gap by blending necessary test prep and reading comprehension strategy practice in a fun, game-based environment. StairStepper is an adaptive literacy skill training game within Interactive Strategy Training for Active Reading and Thinking (iSTART) intelligent tutoring system. StairStepper is unique in that it models text passages and multiple-choice questions of high-stakes assessments, iteratively supporting skill acquisition through self-explanation prompts and scaffolded, adaptive feedback based on performance and self-explanations. This paper describes an experimental study employing a delayed-treatment control design to evaluate users' perceptions of the StairStepper game and its influence on reading comprehension scores. Results indicate that participants enjoyed the visual aspects of the game environment, wanted to perform well, and considered the game feedback helpful. Reading comprehension scores of students in the treatment condition did not increase. However, the comprehension scores of the control group decreased. Collectively, these results indicate that the StairStepper game may fill the intended gap in instruction by providing enjoyable practice of essential reading comprehension skills and test preparation, potentially increasing students' practice persistence while decreasing teacher workload.

Keywords: reading comprehension; strategy training; game-based learning; intelligent tutoring system; feedback

Citation: Arner, T.; McCarthy, K.S.; McNamara, D.S. iSTART StairStepper—Using Comprehension Strategy Training to Game the Test. *Computers* **2021**, *10*, 48. https://doi.org/10.3390/computers10040048

Academic Editors: Carlos Vaz de Carvalho and Antonio Coelho

Received: 16 March 2021
Accepted: 6 April 2021
Published: 9 April 2021

1. Introduction

Literacy refers to "the ability to understand, evaluate, use, and engage with written texts to participate in society, to achieve one's goals, and to develop one's knowledge and potential" [1] (p. 61). Literacy skills are not only critical for educational and career success, but the ability to read and comprehend various text types across multiple subjects is necessary to function in everyday life. However, national reading assessment data suggests that many students struggle with reading comprehension. The most recent National Assessment of Educational Progress [2] on reading skills found that 63% of twelfth-grade students were below proficient in reading. Similarly, 66% of eighth-graders and 65% of fourth-graders were also below proficiency. These numbers suggest that additional instructional support is needed to improve students' reading achievement as they progress through grade levels.

The emphasis placed on standardized testing has increased in the last few decades to ensure that all students (i.e., non-White, lower-income) are receiving equal, high-quality instruction and to monitor adequate yearly progress (AYP) [3,4]. These goals are admirable but have fallen short of the intended targets as many students have failed to learn essential skills and strategies necessary to become part of the global workforce while preparing for standardized assessments [4,5]. Amidst increasing pressure and limited instructional hours, teachers may resort to "teaching to the test" in an effort to demonstrate learning gains on these standardized assessments [3,5,6]. Unfortunately, this practice leads to inaccurate inferences about the knowledge and skills that students have acquired and unreliable inflation in scores on state-level standardized assessments that are not achieved on the NAEP [5,7], nor do these types of tests reflect the types of literacy tasks that the student will encounter outside of the testing room [8,9]. The result is that students fail to develop the comprehension strategies that will better serve them outside of a standardized test [10].

There are multiple barriers to building students' reading comprehension strategies. Developing comprehension strategies requires ample opportunity for cycles of deliberate practice and targeted feedback. One issue is that providing feedback on ill-structured tasks like reading comprehension is both time- and resource-intensive for instructors and students alike. Thus, students have few opportunities to practice with one-on-one support. A second issue is that students may become disengaged from the strategy-building activities before they have mastered the skills [11].

With these issues in mind, we developed a game-based module, StairStepper, to implement an intelligent tutoring system, iSTART. StairStepper was designed to support and reward the use of reading comprehension strategies in the context of a mock standardized reading comprehension test. Our aim was to leverage the power of automated evaluation and game-based principles to offer a scalable, efficient, and fun way for students to develop their reading comprehension skills that can transfer to high-stakes testing environments.

To contextualize StairStepper, we first provide a brief background on the theoretical and educational motivation for reading comprehension strategies as well as an overview of the broader intelligent tutoring system, iSTART, in which StairStepper was built.

1.1. Reading Comprehension Strategies

Theories of discourse comprehension suggest that as learners read, they construct mental models or mental representations of the text information [12]. The mental representation that readers construct as part of comprehension is comprised of multiple levels or layers, which include the (1) surface code, (2) textbase and, (3) situation, model. The surface code includes specific words and syntax but is unlikely to be retained except in cases of rote memorization. This immediate textual information gives rise to the textbase or gist meaning of the text. In the situation model, the reader goes beyond the present text to make inferences and to elaborate from prior knowledge [12–14]. Readers must develop a coherent mental model, beyond the surface level, for text comprehension and knowledge transfer [12,15].

There is ample evidence to suggest that prompting and training students' comprehension strategies improves reading comprehension [16–20]. One such strategy shown to benefit comprehension is self-explanation [21–24]. Generating an explanation to oneself aids in the integration of new information with prior knowledge; these connections support the construction of a more elaborated and durable mental representation of the content [22]. Despite the benefit of using reading comprehension strategies, students may not adopt and use these strategies on their own [10,17,23]. However, there is ample evidence of the benefit of strategy training and practice, specifically self-explanation training [17,23–26], particularly with low-knowledge or struggling students [18,27].

Self-explanation reading training (SERT) improves students' reading comprehension through instruction on five active reading strategies (comprehension monitoring, paraphrasing, predicting, bridging, and elaborating) that lead to generating high-quality self-explanations, which in turn, improves text comprehension [17,18]. The comprehension monitoring strategy encourages the reader to continuously evaluate whether or not they understand what they just read [22]. Comprehension monitoring is an inherent feature of generating self-explanations because if the student is not able to successfully explain what they just read, it is an indication that there is a breakdown in understanding. Thus, comprehension monitoring provides an indicator that the reader needs to employ strategies to repair the gap in knowledge [28]. Skilled readers are more likely to engage in comprehension monitoring, notice inconsistencies in the text, gaps in understanding, and use strategies to repair gaps when they do not understand [28,29]. Paraphrasing is a frequently used strategy in which the reader restates the content of the text in their own words [17]. Although this strategy focuses mainly on developing a textbase, putting the text into one's own words is an important step toward more meaningful processing. A prediction is when the reader speculates about what they think might happen next in the text [17]. While predictions are relatively infrequent during reading, they support comprehension by encouraging the reader to consider more global aspects of the text [30,31]. The last two strategies are similar in that they are both generations of inferences, bridging and elaborative. Bridging inferences are those that connect a statement to a prior sentence or passage in the text. In contrast, an elaborative inference occurs when the reader connects the current text to prior knowledge [32,33]. Generating inferences is an essential component of reading comprehension.

Helping students to use active reading strategies is effective for elementary [34,35], middle [23,26], and high [17,18,36] school students as well as young adults (i.e., college students) [17,37]. However, simply prompting students to use these strategies or providing direct instruction about the strategies is only part of the process of improving students' reading skills. That is, in addition to instruction, students also need ample time to engage in deliberate practice where they are able to use the strategies while receiving feedback on how to improve [38,39]. Although strategy instruction and practice have pronounced benefits for literacy skills [40–42], it is sometimes difficult to keep students engaged and motivated so that they keep practicing. One potential method to encourage the training and practice of these beneficial strategies is through the use of automated intelligent tutoring systems (ITSs) that provide a mechanism for more engaging, game-based practice [39,43,44]. Given the ample evidence of the benefit of strategy training and teachers' limited time to teach strategies, intelligent tutoring systems may be useful in filling that gap as they can provide adaptive feedback inside an engaging, game-based activity that may increase students' motivation to engage in deliberate practice of reading comprehension strategies.

1.2. Intelligent Tutoring Systems

Computers have been used to support learning for the last few decades [45,46], initially in the form of computer-assisted instruction and, more recently, as intelligent tutoring systems (ITSs) [47]. Meta-analyses suggest that computer-assisted instruction (CAI) and ITSs have positive impacts on learning [45,47,48]. ITSs differ slightly from other CAI systems in that they attempt to emulate the one-on-one tutoring experience through adaptive instruction and more granular feedback [46,47,49]. For example, students may receive stepwise feedback (i.e., correct/incorrect, solution hint) during problem-solving (i.e., error detection), and they may also be able to engage in natural dialog with the system emulating a human tutor [37,47]. Comparisons of learning outcomes between human, CAI, and ITS systems suggest that, while the more sophisticated ITSs may be more beneficial to learning than some CAI systems, they are still not quite as effective as human, one-on-one tutoring, which is considered the "gold standard" of instruction [45,47,50]. One feature that may make an ITS system more similar to one-on-one tutoring while also providing actionable feedback and increasing student motivation is the addition of a pedagogical agent [51,52].

Pedagogical agents are characters in technology-based instructional applications designed to facilitate learning [52,53]. The interactions that the agent has with the learner may serve to provide instruction, feedback, or motivation [37,54–57]. The addition of a pedagogical agent may facilitate or increase interaction between the learner and the intelligent tutoring system [58–60]. Pedagogical agents may be a "talking head" that provides information via text or audio comments, or they may be full-body characters who have animated gestures that can be used for additional learning supports, such as signaling [58,59,61,62]. Anthropomorphizing an intelligent tutoring system with a pedagogical agent that has a human-like figure, voice, or both (i.e., *persona effect*) [63] may further increase students' motivation to engage with the intelligent tutoring systems [64–67]. This *persona effect* can lead students to view the engagement with the pedagogical agent as a social interaction similar to what would occur with a human tutor [68]. Thus, students have more positive perceptions of the learning environment and are more accepting of instructions or feedback from the pedagogical agent, which may aid in learning or motivation to persist [59,63,65].

Feedback, broadly defined, is information provided about one's performance. It may also include the difference between one's performance and the learning objective or goal [69,70]. The influence of feedback on student learning outcomes has myriad evidence evaluating its efficacy across task type, subject area and grade levels [71–75]. The general consensus is that feedback has a positive effect on student learning outcomes through the benefit may be moderated by learners' prior knowledge, context, timing, and type of feedback [71,76–79]. Feedback provided by a pedagogical agent in an ITS might be goal-driven (i.e., response correctness), instructional (i.e., hint or strategy suggestion), or affective (i.e., positive reinforcement to continue), which may motivate the learner to continue with the task or practice in the ITS [80,81]. For example, learners with low prior-knowledge experience a greater benefit from explanatory feedback (e.g., "That answer is incorrect because...") than basic corrective feedback (e.g., right or wrong) [77,82].

Students' motivation to engage in a task or persist through struggle is positively related to their achievement [83–86]. The more motivated a student is to engage with a learning task, the more likely they are to complete the task, thereby achieving the learning goal [87]. Motivation to persist in the practice necessary to improve reading comprehension skills may be bolstered by the affordances of ITSs [48], particularly those with anthropomorphized feedback mechanisms (e.g., pedagogical agents) [68] and game-based learning and assessment [39,40,88].

1.3. iSTART

Interactive strategy training for active reading and thinking (iSTART) is an intelligent tutoring system (ITS) based on SERT. iSTART provides self-explanation followed by game-based practice. The iSTART system first provides overview lessons on each of the self-explanation strategies (i.e., paraphrasing, bridging and elaborative inferences, prediction and comprehension monitoring) using video instruction and modeling [89]. During the generative practice, students are given passages to read and then asked to self-explain target sentences. Students' responses are evaluated using natural language processing algorithms that detect evidence of the different comprehension strategies. This algorithm is used to provide a summative score (0–3) as well as formative feedback indicating ways to improve their self-explanation. For example, when responses are too short or too long, Mr. Evans, a pedagogical agent, provides various types of feedback that can help the student to write higher quality self-explanations [26,89,90].

Although the original system demonstrated positive impacts on learner's self-explanation and reading comprehension, it was difficult to keep students motivated in repeated rounds of guided practice. Thus, iSTART-motivationally enhanced (ME) [39,91] introduced additional motivational features via game-based practice. iSTART includes both generative and identification games. In *generative* games, students practice writing self-explanations. For example, students can play "Self-Explanation Showdown", in which they play against a CPU in a head-to-head competition. In *identification* games, students view example self-explanations and need to correctly identify the strategy. Reaching new high scores or levels earns trophies as well as additional "iBucks", the system currency units, which can be used to open and play more games or customize their player avatar. These game-based features support learning in that they may encourage students to engage in prolonged practice, which is critical for developing reading comprehension skills [39,92].

1.4. StairStepper

Building upon iSTART's tradition of game-based literacy practice, StairStepper was designed to provide engaging, a game-based practice that closely approximates question types that students experience in standardized assessments. More specifically, StairStepper gamifies the use of scaffolding to challenge the student to read increasingly difficult texts. Thus, the goal of StairStepper was two-fold; to (1) provide students generative practice of self-explanation strategies that will benefit their reading comprehension skills while simultaneously (2) preparing them for the standardized assessment texts and questions that they will see throughout their educational careers.

1.4.1. Reading Comprehension Strategies for Standardized Testing

Traditional standardized reading assessments are designed to isolate and evaluate reading comprehension skills. For example, The National Assessment of Educational Progress [2] reading assessment is used ubiquitously in K-12 education. The assessment for grade four consists of two texts that students read and then respond to approximately 20 questions that are either selected response (i.e., multiple-choice) or constructed response (i.e., open-ended text entry). The questions are written to assess three types of *cognitive targets* or the kinds of thinking that underlie reading comprehension: locate and recall, integrate and interpret, and critique and evaluate.

The "locate and recall" cognitive target requires students to recall content from the text to answer the question. While students do have the option to refer back to the text, data show that students frequently do not do so [2]. Each of the reading comprehension strategies that students learn about and practice in iSTART can support performance on these types of tests. In StairStepper, like the assessment, students must decide if they *definitely know* the answer to the question, *definitely do not know*, or *might know* the answer. Practicing the comprehension monitoring strategy in the StairStepper game can help students be better prepared to make a clear decision about what they do and do not know when responding to questions. The second target, "integrate and interpret," requires students to make complex inferences within and across texts to derive meaning, explain a character's motivation or action, or uncover the theme of the text. The bridging and elaboration strategies that are practiced in StairStepper are the same strategies that are used to make these complex inferences when responding to the "integrate and interpret" target questions. The third question type, "critique and evaluate", requires students to think critically about text and evaluate aspects of it using a variety of perspectives based on their knowledge of the world. The paraphrasing and elaboration strategies encourage students to think about the text in ways as if they were going to explain it to another while also using their knowledge of the world to make sense of the content. Despite the benefit of reading comprehension strategies, they are often put to the side as teachers focus on preparation for standardized tests when, in fact, these strategies can and should be leveraged in standardized testing environments.

1.4.2. Text Set and Questions

The first step in designing the StairStepper game was to develop and evaluate a corpus of texts and corresponding questions that would emulate these standardized assessments. The texts and their accompanying questions were retrieved from publicly available educational resources. The text topics span multiple domains, including knowledge gained in school (i.e., science and social science) and knowledge gained in daily life (i.e., sports and pop culture). Texts range from seven to 80 sentences in length. Rather than relying on shallow measures of readability, the texts were leveled through comparative judgments made by independent raters (for description, see [93]). The initial set of 172 texts was separated into 12 levels of increasing difficulty. These rater judgments of difficulty were correlated with both Flesch–Kincaid grade level (r = 0.79) and Dale–Chall readability (r = 0.77) [94]. After inspection and piloting, the final text set was reduced to 162 leveled texts chosen to mimic those students may see in reading comprehension assessments taken in classrooms every year.

The full corpus of multiple-choice questions from these texts was piloted to check for floor and ceiling effects. Some items were removed or slightly edited for clarity. The remaining items were then categorized by question type based on the source of the knowledge required to answer the questions correctly. Questions categorized as *textbase* ($N = 677$) can be answered from information found in a single sentence in the text. *Bridging inference* questions ($N = 160$) require the reader to combine information from two or more sentences in the text. Finally, *elaboration* questions ($N = 144$) require the reader to use the information found in the text and prior knowledge to answer correctly. Lower level texts (below level 8) have a higher percentage of textbase questions (>70%), whereas the higher-level texts (level 8 and above) had fewer textbase questions (35–45%) and more bridging inference (45–55%) and elaboration (8–10%) questions.

The texts and question types used in StairStepper are representative of various standardized assessments that students are likely to encounter in their educational careers. Therefore, these questions may be useful in helping students prepare for standardized assessments. Furthermore, StairStepper also provides students a more engaging way to practice reading comprehension strategies that are supported by evidence from numerous studies [17,18,90]. The underlying benefits of practicing these strategies inside the StairStepper game are that students may be more motivated to persist in practice, and they may be more likely to transfer the strategy used to the standardized assessments taken in the future.

1.4.3. Game Play

The goal of StairStepper is to ascend to the top stair by answering comprehension questions about increasingly difficult texts. Students begin the game with instructions on their task and a reminder of the strategies (comprehension monitoring, paraphrasing, prediction, bridging, elaboration) that they can use when writing self-explanations.

The game begins with the student's avatar on step five of twelve, where they are presented with a text of low-moderate difficulty (iSTART's default setting begins at level 5, but this is an adjustable feature). In the first text, they are not prompted to self-explain. At the end of the passage, they are asked to answer a series of multiple-choice questions about the text. Students who meet the correct response threshold (75%) on the multiple-choice questions are promoted to the next step and begin a new, slightly more difficult passage. In contrast, students who answer less than 75% of the question incorrectly receive another text at the same level. In this second text, the student is prompted to self-explain at various target sentences. In the first phase of scaffolding, students receive a score of the quality of their self-explanation on a color-coded, four-point scale ranging from Poor to Great (See Figure 1).

As depicted above, the StairStepper game includes iSTART's Mr. Evans, who serves as a guide through the game-based practice. He provides three types of information to students during gameplay; task instructions, feedback, and progress messages. The task instruction messages let students know what they need to do or what will happen next. For example, when the student begins StairStepper, Mr. Evans tells them that they will read the text and answer the questions (see Figure 2). Statements like this are provided any time there is a change in procedure, such as when a student moves between scaffolded levels.

Second, Mr. Evans provides feedback to the students. One type of beneficial feedback is motivational (i.e., praise) [47,49,52], such as telling the student, "Great, you got that one right." when they answer a multiple-choice question correctly (Figure 3). Mr. Evans will also provide metacognitive prompts that require students to think about and identify what self-explanation strategy they used (bridging, elaboration, paraphrasing) [17].

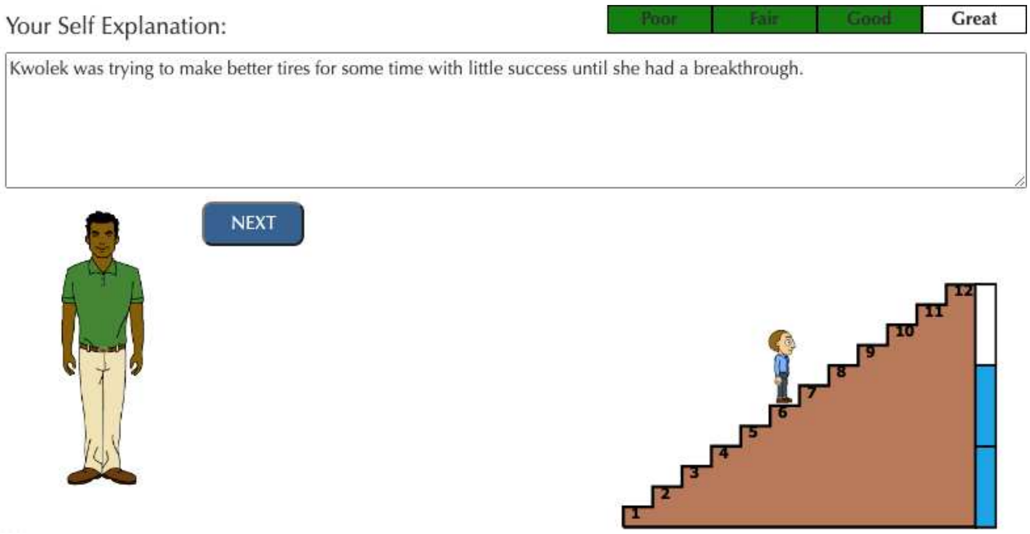

Figure 1. Players receive feedback on their self-explanation quality from the system.

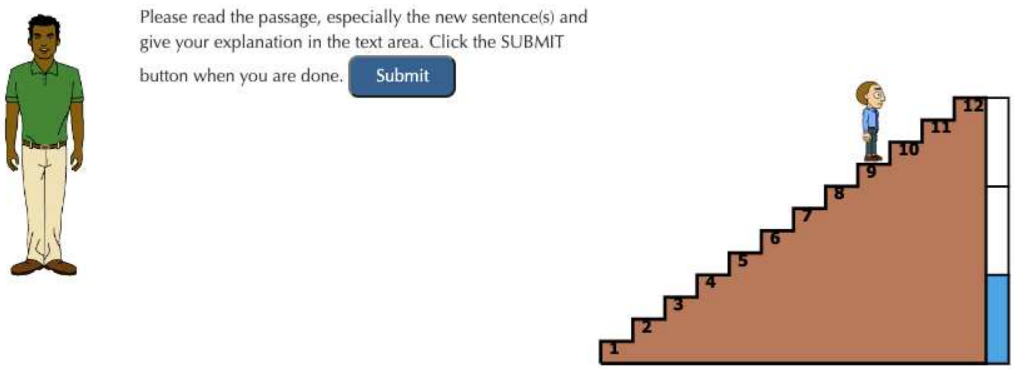

Figure 2. Mr. Evans gives the player instruction on what will happen next in the game.

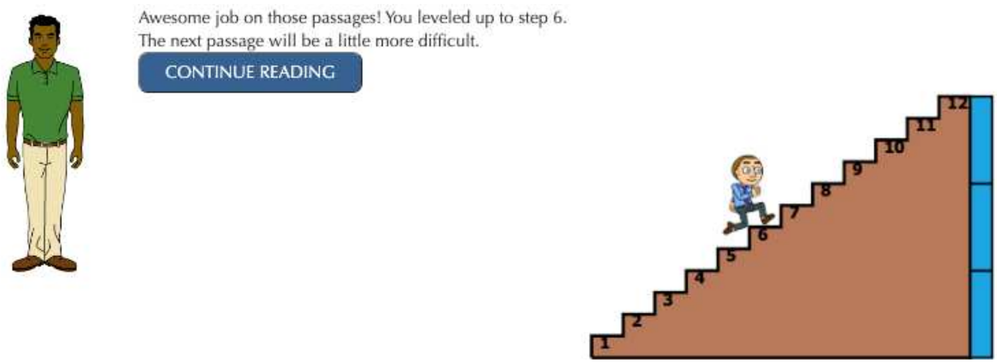

Figure 3. Mr. Evans provides feedback on comprehension practice. Player avatar moving up to the next level.

After submitting their self-explanations for the entire text, students are given between 5 and 20 multiple-choice questions, depending on the text. If the student again receives a score below the threshold (75%), the next text includes prompting for self-explanation and feedback on the quality of the self-explanations with an opportunity to revise. Thus, students can receive three support levels (no SE, SE, SE + feedback; see Figure 4). If the student continues to struggle, the text difficulty is decreased, and as their comprehension improves, the subsequent texts become more challenging. Students' progress through the game follows this same cycle of assessing comprehension at each level of text difficulty, and when the minimum is not met, students are provided scaffolded strategy training and feedback to aid in text comprehension.

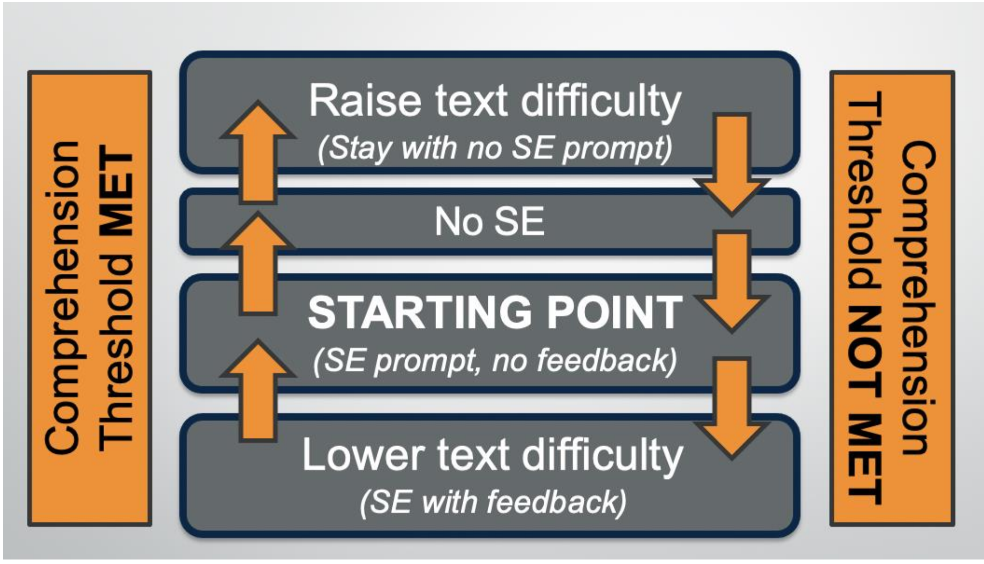

Figure 4. Scaffolded support process in the StairStepper game.

1.5. Present Study

The iSTART research team continues to refine and evolve the types of game-based activities available in the ITS. The purpose of the present study was to investigate the effects of the new game-based adaptive literacy module, StairStepper. More specifically, we examined the potential benefit of the scaffolded support design of the StairStepper game on students' perceptions and motivations, as well as the effects of short-term practice with StairStepper on reading comprehension skills. We sought to answer three research questions with the present study.

1. How do students respond to the StairStepper game-based practice?
2. How will participants progress through the StairStepper game based on text adaptivity and scaffolded feedback?
3. How do iSTART training and StairStepper practice influence participant performance on a comprehension test and standardized assessment?

College students (n = 51) completed the iSTART lesson videos and a round of Coached Practice. They then engaged in 90 min of StairStepper practice. Students were asked to complete a questionnaire about their experiences to measure their enjoyment and interest in the game-based practice and their self-reported sense of learning. To explore the efficacy of StairStepper, half of the participants (n = 25) were assigned to a 3-day treatment condition that received a pretest, iSTART/StairStepper, and then a post-test. The other half (n = 26) were assigned to a delayed treatment control in which they completed a pretest, a post-test, and then the iSTART/StairStepper training. We hypothesized that students in the StairStepper treatment condition would show pretest to post-test improvement on the proximal outcome of standardized Gates–MacGinitie reading test (GMRT) score and the more distal comprehension scores.

2. Results

2.1. Perceptions of the StairStepper Game

Our first question regarded students' enjoyment of StairStepper. Our purpose for building StairStepper was to include a fun and motivating test prep module in a way that aligned with the purpose of iSTART (reading comprehension strategy training). Thus, it was important to investigate the extent to which participants enjoyed the game-based features of StairStepper. To this end, we asked students to answer survey questions regarding their experiences and perceptions of StairStepper. These analyses include 48 students, including those in the delayed treatment control, who played StairStepper after their post-test assessment. Three students did not complete the perceptions portion of the study.

As shown in Figure 5, participants rated their experience with the game interface (e.g., objects in the game) and game features (e.g., visual appearance) as well as personal attributes as they related to learning in game environments (e.g., goal setting). Overall, participants had positive attitudes about the StairStepper game as a method to practice reading comprehension strategies (see Figure 5).

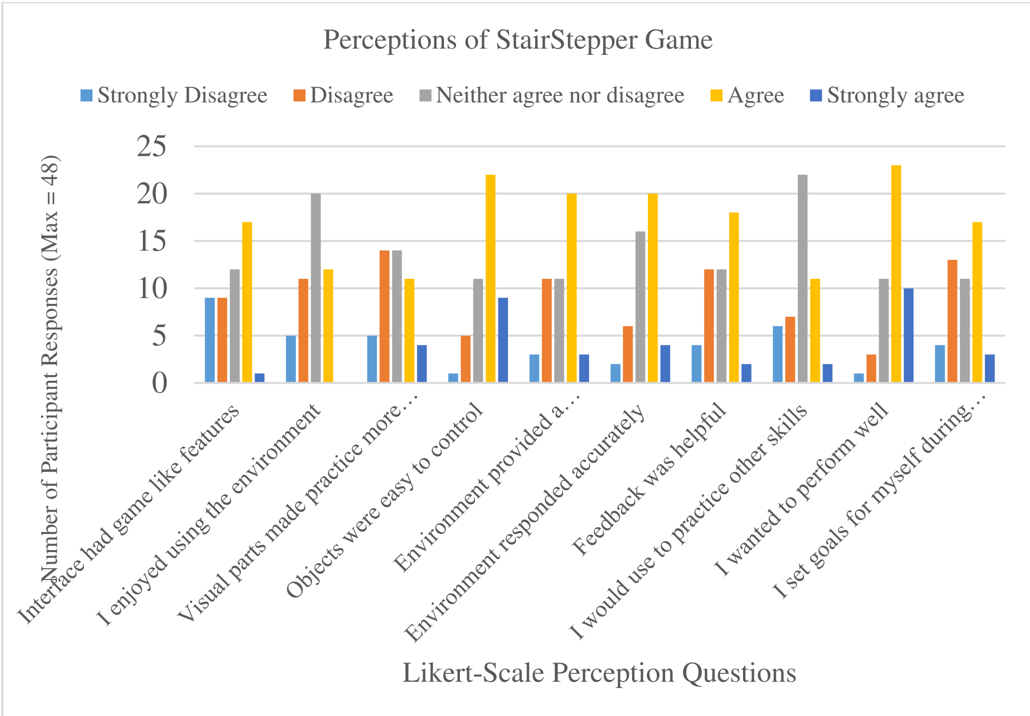

Figure 5. Participant responses on 5-point Likert scale questions on perceptions of the StairStepper game. Three participants did not complete the perceptions survey.

We conducted Wilcoxon signed-rank tests to evaluate whether or not participant responses were significantly different from neutral. Results revealed that three items were indeed significantly positive: "Objects were easy to control" ($p < 0.000$); "Environment responded accurately" ($p = 0.02$); and "I wanted to perform well" ($p < 0.000$). The other perceptions items were not significantly different from neutral, suggesting that the students did not have negative opinions of StairStepper.

We further analyzed participants' perceptions of the StairStepper game as a function of reading skill using a median split on the GMRT pretest scores to determine the influence of reading skill on participants' perceptions of the StairStepper game (see Table 1). Results indicated a significant difference on participants' agreement with "Enjoyed the practice environment" ($t(1, 45) = 3.45$, $p = 0.001$), "Interface had game-like features" ($t(1, 45) = 2.16$, $p = 0.04$), and "I would use for other skills" ($t(1, 45) = 1.98$, $p = 0.005$). These results suggest that participants who had lower reading comprehension skills found the StairStepper game more enjoyable than those who were more proficient in reading. These results may stem from proficient participants not believing that they were benefiting from the StairStepper practice module.

Table 1. Participant perceptions of the StairStepper game in iSTART.

Question	Reading Skill Level	*N*	Mean (SD)	*t*	*p*
Enjoyed the practice environment	Low	21	3.29 (0.72)	3.45	0.001 **
	High	26	2.42 (0.95)		
Feedback was helpful	Low	21	3.33 (0.91)	1.84	0.073
	High	26	2.77 (1.14)		
Interface had game-like features	Low	21	3.24 (0.94)	2.16	0.0360 *
	High	26	2.54 (1.27)		
Provided a purpose for actions	Low	21	3.33 (1.02)	0.938	0.353
	High	26	3.04 (1.11)		
I set goals during practice	Low	21	3.19 (1.12)	0.809	0.423
	High	26	2.92 (1.13)		
Visual appearance made the practice more enjoyable	Low	21	3.19 (1.03)	1.62	0.111
	High	26	2.65 (1.20)		
Objects were easy to control	Low	21	3.67 (0.97)	−0.22	0.826
	High	26	3.73 (1.00)		
I wanted to perform well	Low	21	3.71 (0.85)	−0.479	0.634
	High	26	3.85 (1.00)		
I would use for other skills	Low	21	3.24 (0.83)	1.98	0.054 *
	High	26	2.65 (1.13)		
Environment responded accurately	Low	21	3.43 (0.98)	0.287	0.775
	High	26	3.35 (0.98)		

Note: * $p < 0.05$, ** $p < 0.01$.

2.2. System Data

Our second question regarded students' traverse through the system in terms of whether they descended or ascended the "stairs" or text difficulty. To this end, we conducted a visual inspection of the log data. Figure 6 shows each participants' trajectory through StairStepper with text number along the x-axis and text difficulty along the y-axis. The participants are ordered based on their pretest GMRT score and color-coded accordingly. This visual inspection demonstrated two important findings. First, the game architecture was responsive to participants' reading skills. Participants with lower GMRT scores were given less difficult texts; more skilled readers ascended to the most difficult texts more quickly. Second, these graphs also demonstrate that many of the participants showed some decreases and increases in text difficulty, suggesting that the different amounts of scaffolding (self-explanation, feedback, text leveling) were effectively providing just-in-time support.

2.3. Reading Comprehension

Our third question regarded the impact of StairStepper on reading comprehension skills. Reading skills are generally impervious to relatively brief treatments, as in this study. For example, observed increases in self-explanation and comprehension skills generally have required at least 4 to 8 h of instruction and practice [17,18,39]. Yet, given that students in the StairStepper treatment condition received explicit instruction and practice on self-explanation and comprehension strategies, one of our objectives was to examine the extent to which this brief game-based practice impacted their ability to comprehend challenging science texts as well as their performance on the GMRT and comprehension of a science text. The GMRT texts are similar to the practice texts in StairStepper, whereas the science text included textbase and open-ended inference questions. Descriptive data and correlations between the measures are presented in Table 2.

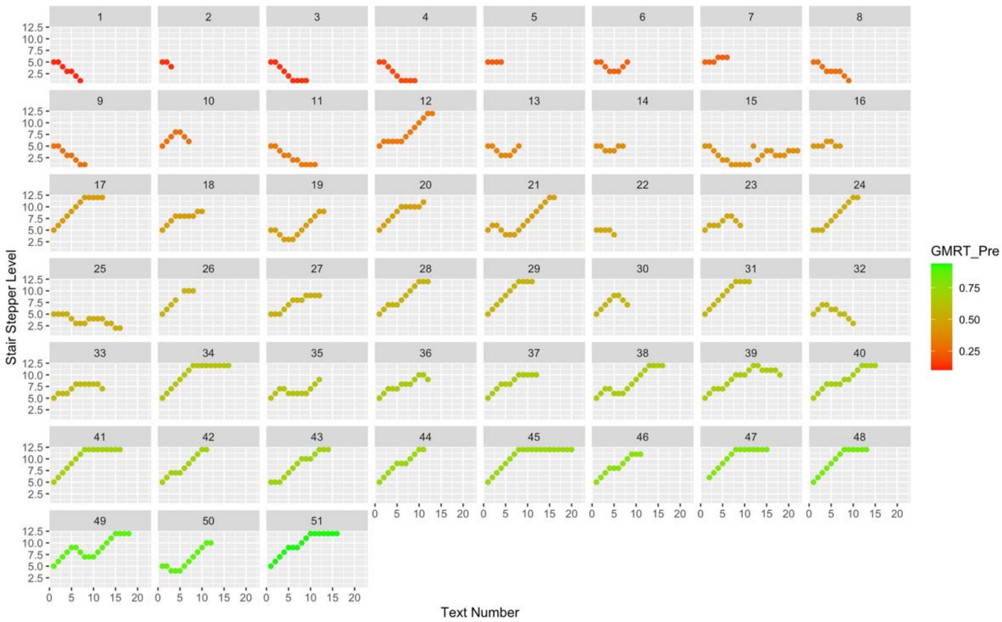

Figure 6. Participants' log data shows their progression through the StairStepper texts (number along the *x*-axis) as a function of text difficulty at each level (*y*-axis). These data revealed two system issues: (1) the "jump" in participant 15's data reveals a system crash, and (2) several of the more skilled readers should have "won" the game after completing two levels 12 texts (e.g., 45). However, system settings prevented the game from ending. These issues were reported to the programmer and addressed.

Table 2. Descriptive statistics for comprehension measures.

Test	Mean (SD)	1	2	3	4	5	6	7	8
1. GMRT Pretest	0.50 (0.21)	1.00							
2. GMRT Posttest	0.50 (0.24)	0.89 **	1.00						
3. Pretest Mean	0.35 (0.21)	0.56 **	0.62 **	1.00					
4. Posttest Mean	0.36 (0.21)	0.65 **	0.67 **	0.63 **	1.00				
5. Pretest Textbase	0.28 (0.23)	0.44 **	0.48 **	0.85 **	0.52 **	1.00			
6. Posttest Textbase	0.41 (0.24)	0.57 **	0.60 **	0.57 **	0.87 **	0.49 **	1.00		
7. Pretest Inference	1.66 (1.01)	0.53 **	0.59 **	0.88 **	0.57 **	0.50 **	0.50 **	1.00	
8. Posttest Inference	0.32 (0.24)	0.57 **	0.57 **	0.53 **	0.87 **	0.42 **	0.51 **	0.49 **	1.00

Note: pretest text is *Red Blood Cells*, and post-test text is *Cell Repair* to assess comprehension of challenging science texts. ** $p < 0.01$.

We conducted preliminary analyses to examine whether there was a significant difference in reading comprehension skills between groups. Results of an independent samples t-test conducted on participants' GMRT pretest scores indicated that there was a significant difference ($t(1, 53) = -2.59$, $p = 0.012$) in pretest means between the delayed treatment control ($M = 0.44$, $SD = 0.22$) and the StairStepper training condition ($M = 0.58$, $SD = 0.19$). Similarly, results of independent samples t-test conducted on students' science comprehension (i.e., *Red Blood Cells*) pretest mean scores indicated a significant difference ($t(1, 53) = -2.13$, $p = 0.038$) in mean scores between the delayed-treatment control ($M = 0.30$, $SD = 0.19$) and the StairStepper training condition ($M = 0.42$, $SD = 0.22$). As such, pretest scores were included as covariates in the analyses to control for prior reading skills.

2.3.1. GMRT

We examined the extent to which 90 min of StairStepper practice impacted performance on a standardized reading comprehension measure. To account for group differences, we conducted a t-test on pretest to post-test change scores to evaluate the impact of the StairStepper practice game on students' reading comprehension. Results indicated that there was a significant difference in pretest to posttest change ($t(1,49) = -2.72$, $p = 0.009$; Figure 7) between the StairStepper training group ($M = 0.04$, $SD = 0.12$) and the delayed treatment control ($M = -0.04$, $SD = 0.09$). While we did not have hopes of observing substantial gains from such a short training session and single, 90 min practice session on a standardized test, such as GMRT, these results suggest that the StairStepper practice game has strong promise in helping students to improve their reading skills and performance on similar tests.

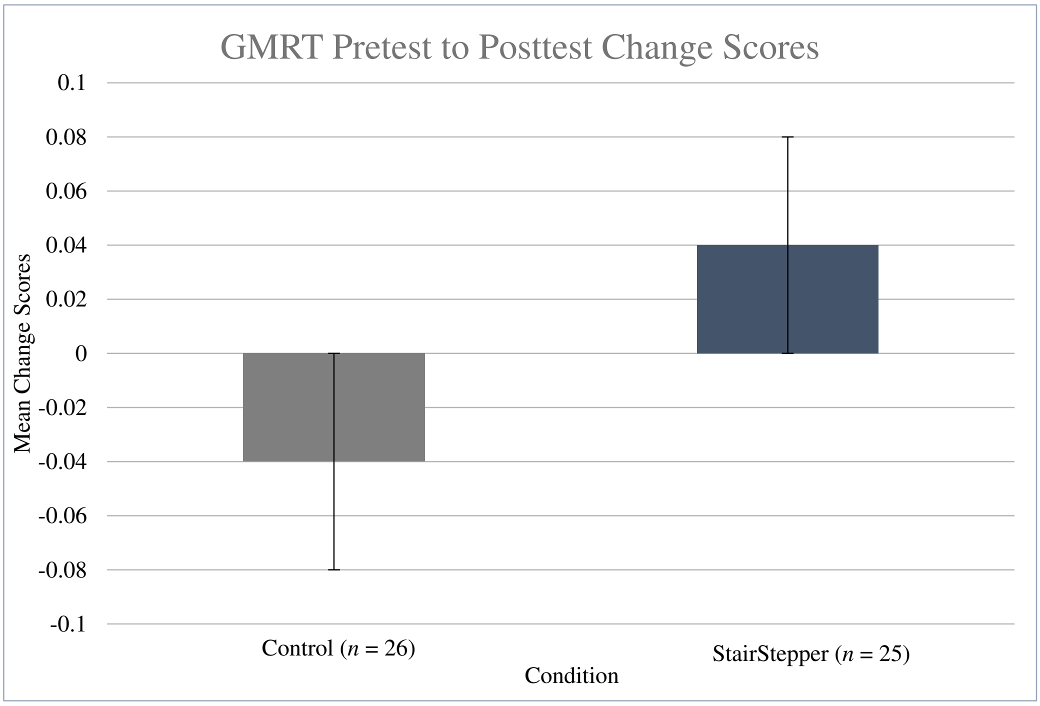

Figure 7. Gates-MacGinitie reading test (GMRT) pretest to post-test change as a function of condition. Error bars indicate standard error.

2.3.2. Science Comprehension

A 2 (question type: textbase, bridging inference) by 2 (condition: control, StairStepper training) analysis of covariance (ANCOVA) was conducted to examine the effect of StairStepper training on the two different question types. Item type was included as the within-subjects factor, condition as a between-subject factor, and performance on the pretest comprehension test was included as a covariate. There was no significant effect of question type, $F(1, 48) = 0.580$, $p = 0.45$, nor was there any effect of StairStepper training $F(1, 48) = 1.28$, $p = 0.26$). There was also no interaction effect, $F(1, 48) = 1.21$, $p = 0.27$ (Figure 8).

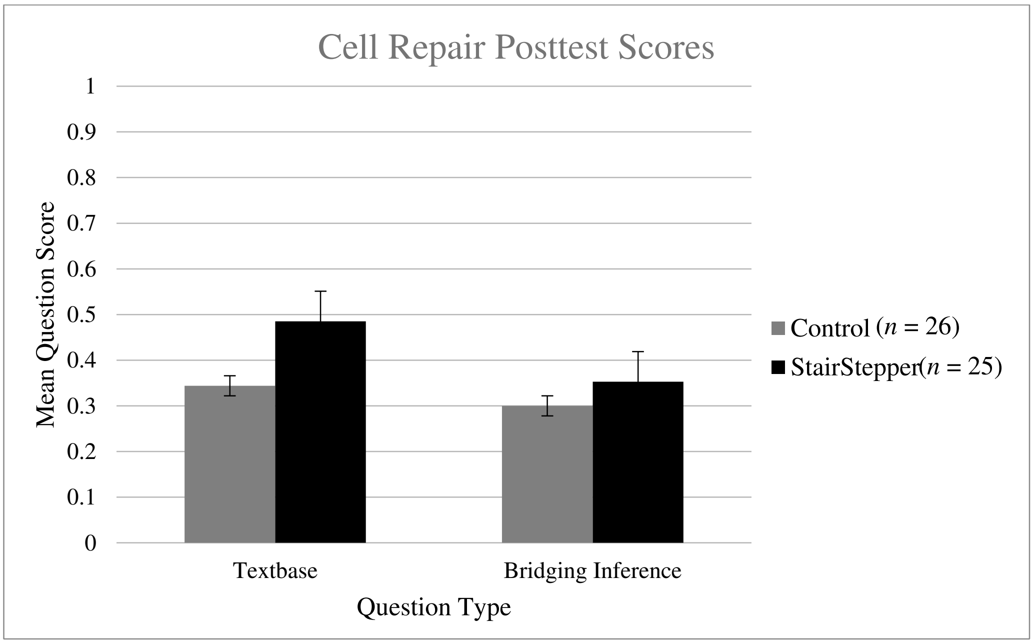

Figure 8. Comprehension question scores as a function of question type and condition.

3. Discussion

The present study investigated a new game designed to provide students with an engaging environment to practice reading comprehension strategies while simultaneously preparing for standardized reading comprehension assessments. StairStepper, housed in the iSTART intelligent tutoring system, uses adaptive text and scaffolded feedback support to guide students through self-explaining and answering questions about increasingly challenging texts. The goal of this study was to evaluate participants' perceptions of the new game and to examine the possible benefits of StairStepper practice as measured by lab-designed comprehension measures and standardized (GMRT) performance.

Results indicated that participants had positive attitudes about the StairStepper game as a way to practice the reading comprehension strategies. Specifically, participants considered the objects in the environment to be easy to control and that the game provided an accurate reflection of their performance. In addition, of note is that a significant number of participants reported "wanting to do well" while engaging with the system. Indeed, these results align with prior work on the use of the game-based practice to support students' motivation and engagement [39]. Interestingly, the participants, who had lower reading comprehension skills, had more positive attitudes about the game environment and the game features. Furthermore, they indicated that they would use this game to practice different types of skills. One explanation for these results is that the benefit of gameplay may have been more salient to those participants who had lower reading comprehension skills. These results align with prior research indicating that the students who have lower reading comprehension scores garner a greater benefit from self-explanation reading training [18,36] and strategy training in iSTART [95]. While these studies investigated self-explanation reading training and reading comprehension training in iSTART for longer durations, the participants' perceptions of StairStepper in the present study are promising.

We evaluated the influence of iSTART training and StairStepper practice on participants' scores on a standardized reading assessment (i.e., Gates–MacGinitie reading test, GMRT). Preliminary results indicated that there was a significant difference between groups at the pretest. To account for differences between groups, we analyzed change scores from pretest to post-test on the GMRT and found that the participants in the StairStepper game condition maintained their reading comprehension score, while those in the delayed treatment control experienced a significant decrease in comprehension score from pretest to post-test. These results suggest that the StairStepper practice game benefited participant maintenance and use of the reading comprehension strategies. This aligns with prior research suggesting that reading comprehension strategies need to be practiced in order for students to consistently adopt and use them [40,41].

This study also investigated the influence of the short iSTART training session followed by 90 min of practice on the StairStepper game on participants' reading comprehension scores. The results indicate no significant effects of training on open-ended comprehension scores. These results may reflect the need for larger sample sizes to detect effects as a function of pre-training differences. That is, pretest scores on comprehension and GMRT were strongly predictive of post-test scores. Given that less-skilled readers found the game more valuable, it may be that these students would benefit more from StairStepper and from extended practice. Indeed, these results suggest that students may need more training and practice than occurred in this study (i.e., one session of training and one session of practice). Evidence from prior studies indicates that consistent adoption of strategy use requires extended, deliberate practice [95]. Therefore, additional work is needed to investigate the number of practice sessions that may result in participants' efficient use of different types of reading strategies and the extent to which this supports performance on textbase and bridging question performance.

Taken together, these results suggest that the students who received self-explanation strategy training and StairStepper game-based practice did benefit in that their reading comprehension scores remained stable. Conversely, participants in the delayed-treatment control group experienced a significant decrease over the course of the three-day study. While we did not expect to see an increase in reading comprehension skills after a short training and practice session, these results indicate that there is a benefit to students' motivation to perform well on the test. Further work is needed to evaluate the practice dosage (i.e., number of sessions) and duration (i.e., length of sessions) that may lead to long-term improvement in reading comprehension skills. Additionally, larger studies will also allow us to more rigorously investigate how StairStepper training varies across different individual differences, such as reading skills.

The positive attitudes that participants reported about the StairStepper game and the maintenance of reading comprehension scores on a standardized assessment are promising. The goal of this work was to develop a game-based module in the iSTART intelligent tutoring system that would be engaging for students to practice using self-explanation strategies while also preparing them for the standardized assessments that they will experience throughout their educational career. Additional work is needed to investigate the dosage (i.e., how many practice sessions) and the durability (i.e., how long will strategy adoption last) that is most beneficial for this type of game-based practice. In sum, the StairStepper game-based practice module may serve an important role in students' acquisition of and long-term adoption of self-explanation strategies that contribute to reading comprehension and literacy skills.

Limitations and Future Directions

While the results of this study are promising, we acknowledge some limitations that should be considered in future work. First, the StairStepper game was designed as an engaging way for high school students to practice self-explanation strategy use while preparing for standardized assessments that are common throughout K12 education. However, our sample comprised undergraduate students who were earning course credit as part of the participant pool. As demonstrated by some ceiling effects in our data, several of our participants were skilled readers. These students are less likely to substantially benefit from this practice game in this context. However, there were also a number of undergraduates in our sample who did not immediately reach the highest level in the game. Thus, we will continue to explore the student characteristics and contexts under which StairStepper practice could be most beneficial. To this end, future work will broaden the scope of the participant pool to include a diverse sample of secondary students to evaluate the efficacy of the intervention with the target population.

Second, the current study relied on a small sample completing only 90 min of practice. We are developing additional studies in which larger, more diverse samples of students complete extended training and practice. Such studies will allow us to better detect and articulate the effects of self-explanation training and deliberate strategy practice using the StairStepper game in iSTART.

4. Materials and Methods

4.1. Participants

The participants in this study were 55 undergraduate students from a large university in the southwest. A demographic questionnaire indicated the sample was predominantly male (female = 38.2%, male = 61.8%, M_{age} = 19.83 years) and the sample was 1.8% African American, 36.4% Asian, 40% Caucasian, 16.4% Hispanic and 7% identified as other. English was not the first language for 38.2% of the participants. The final analyses included 51 participants as 4 were unable to complete the study in the allotted time.

4.2. Learning Measures

Participants' reading comprehension was measured using the Gates–MacGinitie reading comprehension test (GMRT, grades 10–12) [96] at pre- and post-test. Forms S and T were counterbalanced across participants such that those who were given form S at pretest were given form T at post-test or the reverse, in the training and delayed treatment control.

All participants also completed pretest and post-test comprehension assessments. The pretest text was titled *Red Blood Cells,* and the post-test text was titled *Cell Repair.* The pretests and post-tests include textbase questions (i.e., those that can be answered directly from the text) and bridging inference questions (i.e., those that require students to make a bridging inference between two sentences in the text).

4.3. Perceptions Measures

Participants completed a survey following their interaction with iSTART and the StairStepper practice game. Participants rated their experience with iSTART and StairStepper, including their enjoyment of the game and its features. Participants were also asked to rate their performance using the system. Items were rated on a 5-point Likert scale from (1) strongly disagree to (5) strongly agree.

4.4. Procedure

Participants self-selected into study A (delayed-treatment control) or study B (training condition) through the SONA research participant sign-up system. Scheduling of study (A) and study (B) was counterbalanced across weeks to prevent selection bias. Participants in Study A and Study B completed the same tasks for this experiment. Participants in the training condition experienced the intervention between the pretests and post-tests (see Table 3). However, participants in the delayed-treatment control experienced the intervention, iSTART self-explanation training and playing the StairStepper game during Session 3. This design allowed us to compare conditions while not depriving the control group of instruction and practice using StairStepper.

Table 3. Delayed treatment and training group session activities.

Study	Session 1	Session 2	Session 3
A (delayed-treatment control)	Demographics questionnaire, GMRT pretest, self-explanation and comprehension test for *Red Blood Cells*	GMRT post-test, self-explanation and comprehension test for *Cell Repair* iSTART self-explanation instruction (60 min)	90 min playing StairStepper
B (training)	Demographics questionnaire, GMRT pretest, self-explanation and comprehension test for *Red Blood Cells* iSTART self-explanation instruction (60 min)	90 min playing StairStepper	GMRT post-test, self-explanation and comprehension test for *Cell Repair*

5. Conclusions

Results from standardized reading assessments suggest that many students struggle to develop proficiency in literacy skills that are critical to educational and career success. Unfortunately, these test results, in conjunction with limited time and resources, often lead instructors to focus on preparing students for the high-stakes assessments rather than helping them to develop more generalizable reading comprehension skills [3,5]. The StairStepper game in iSTART was designed to address these potentially competing objectives by offering an automated, game-based practice environment that supports students' learning of reading comprehension strategies while also preparing them for high-stakes assessments. This study sought to answer three research questions; (1) How do students respond to the StairStepper game-based practice?; (2) How will participants progress through the StairStepper game, based on text adaptivity and scaffolded feedback?; (3) How to do iSTART training and StairStepper practice influence participants' performance on a comprehension test and standardized assessment?.

This study suggests that students enjoyed the game interface, attempted to perform well, and found the gameplay to be motivating. Specifically, they believed that it had game-like features and indicated that they would use this type of game to practice other skills. Regarding research question two, system data analysis results suggested that students progressed through text difficulty levels successfully and benefited from the scaffolding and feedback process. Finally, the results suggested that the scores of students who played the StairStepper game remained stable, whereas the students who did not receive training and play the StairStepper game demonstrated a decrease in their reading comprehension scores. Collectively, these results suggest that iSTART training and StairStepper game-based practice were beneficial for students reading comprehension strategy use. This initial student suggests promise for implementing StairStepper into the classroom and into test prep and as a positive step toward helping students to excel in high-stakes testing and beyond.

Author Contributions: Conceptualization, K.S.M. and D.S.M.; methodology, K.S.M. and D.S.M.; formal analysis, T.A. and K.S.M.; investigation, K.S.M.; resources, D.S.M.; data curation, K.S.M.; writing—original draft preparation, T.A.; writing—review and editing, T.A., K.S.M., and D.S.M.; visualization, T.A.; supervision, D.S.M.; funding acquisition, D.S.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by The Office of Naval Research through Grant number N00014-20-1-2623. The opinions expressed are those of the authors and do not represent views of the Office of Naval Research.

Institutional Review Board Statement: The study was conducted according to the guidelines of the American Psychological Association and approved by the Institutional Review Board of Arizona State University (00011488, 10 February 2020).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data may be accessed by emailing the first author at tarner@asu.edu.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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Review

Serious Games and the COVID-19 Pandemic in Dental Education: An Integrative Review of the Literature

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Abstract: The COVID-19 pandemic has forced faculties including dental schools into a 'new normal', where the adoption of remote or distance learning is required to minimise the risk of infection. Synchronous learning historically was favoured due to the perceived advantage of 'real time' interactions between instructors and learners; these interactions are not always possible in asynchronous settings. However, serious games can overcome this limitation of asynchronous learning. This integrative review explores the literature on serious games in dental education, to construct a conceptual framework of their strengths in this pandemic. Following consideration of inclusion and exclusion criteria, 15 articles on 11 serious games designed for dental education were included in this review. Our investigation points to an increase in the use of serious games since 2018. The findings of the review support the use of serious games in dental education during the recent crisis. Key strengths include positive educational outcomes, enhanced engagement and motivation, interactive asynchronous distance learning, a safe learning environment, and the advantage of stealth assessment. Consequently, the 'new normal' in education appears to support a very promising future for serious games, particularly in dental education. A conceptual framework is proposed to inform further research across all education settings and timeframes.

Keywords: asynchronous learning; COVID-19; dental education; distance learning; game analytics; game-based learning; integrative review; remote learning; serious games

Citation: Sipiyaruk, K.; Hatzipanagos, S.; Reynolds, P.A.; Gallagher, J.E. Serious Games and the COVID-19 Pandemic in Dental Education: An Integrative Review of the Literature. *Computers* **2021**, *10*, 42. https://doi.org/10.3390/computers10040042

Academic Editors: Carlos Vaz de Carvalho and Antonio Coelho

Received: 28 February 2021
Accepted: 25 March 2021
Published: 1 April 2021

1. Introduction

The COVID-19 pandemic has been rapidly spreading around the world due to the SARS-CoV-2 virus. This outbreak has impacted on varied areas, including participation in the educational field at all levels. Students are not allowed to conduct learning activities on campus as they need to minimise the risk of COVID-19 infection. Technology-enhanced learning (TEL), especially in a remote or distanced setting, enables instructors and students to control time, location, and pace, which are weaknesses of traditional education [1,2]. Consequently, TEL can be helpful in this pandemic where distance learning is required.

'Remote' or 'distance learning' can be conducted in either synchronous or asynchronous formats [3]. The term distance learning will be used within this paper. Both synchronous and asynchronous formats have advantages and disadvantages. During the pandemic, synchronous learning employed videoconferencing and webinars to replace face-to-face teaching. It allowed instructors and students to have interactivity in real time [4]. Asynchronous learning has readily been implemented for a period to improve flexibility. It allows students to learn at any time, but there could be a problem with the absence of real-time interactivity between instructors and learners [4]. However, serious games are advanced technological tools that can be implemented to enhance interactivity in asynchronous learning.

Serious (rather than for entertainment purposes) games are those primarily designed for education and training [5]. They allow students to improve their competences using feedback provided by the game system until they complete a game task [6,7]. Students can be engaged while learning through the game components [8,9]. Safe learning environments can also be created within serious games for students in various fields including healthcare [10–13]. A rapid review of serious games in healthcare education found that they can offer a similar educational outcome to traditional strategies, but the learning approach used in games seems to be more engaging [11]. These arguments support the use of serious games in disciplines such as healthcare education.

In the current global context, where learning in face-to-face settings or in real situations is restricted, serious games should be considered as tools to enhance interactivity in healthcare education including dental education. In our recent review in 2018 we reported that serious games had been implemented in various fields in healthcare education, but very few had been developed to be used in dentistry [11]. As there had not been a review of the use of serious games in dental education since our rapid review, it was considered necessary to conduct this integrative review to explore developments in this fast-changing field and to evaluate their impact when used in extraordinary circumstances such as the COVID-19 pandemic. This would give us the opportunity to investigate whether there has been an increase in use of serious games in dental education since 2018.

2. Theoretical Background of the Review

Serious games have the advantage of combining game-based learning and TEL. The learning process within an educational game comprises the instructional content and the game characteristics, and these two components trigger a game cycle, where students are motivated to learn [14], the game cycle being an iterative learning process that engages user judgement, user behaviour and system feedback to lead to achievement of learning outcomes [14]. This model can be implemented to explain the concept of serious games [10]. The learning process in serious games can be further explained by the important role that failure plays [6]. Failure within the game allows users to improve their competence to complete a game task. Furthermore, entertaining components are required for serious games to engage users in the game cycle [5,14], otherwise users may stop playing before they can achieve the expected learning outcomes.

Performance assessment is another consideration when using a serious game. In the game engine, interaction between users and a game system (user-generated data) can be captured without interrupting the learning process, i.e., so called stealth assessment [7]. These serious game analytics will reveal how the competence of learners can be improved with formative feedback until game completion. Enhanced with TEL, serious games can provide immediate feedback, enabling students to recognise mistakes and reconsider strategies to complete the game [6]. The immediate feedback within a serious game can support users to learn from their experiences.

Since the outbreak of the COVID-19, social distancing has been recommended to minimise the infection risk, and therefore onsite learning in dental schools has been restricted. During this period, there has been more focus on remote online synchronous learning as a substitute for face-to-face settings, as instant feedback can be provided through real-time interactivity [15,16], with an argument that immediate response may not be possible in asynchronous learning [17,18]. However, immediate feedback is considered an important feature of serious games [19,20]. In addition, with TEL support, serious games may be used anytime and anywhere [2], and therefore they have the potential to create interactive learning environments for asynchronous settings in dental education. Consequently, serious games might overcome the limitations of other asynchronous learning approaches and help students to gain knowledge and skills with engagement and motivation during the COVID-19 pandemic. This integrative review aimed to analyse the literature concerning serious games in dental education, in order to construct a conceptual framework of their strengths in response to the COVID-19 pandemic.

3. Methods

An integrative review of the literature was selected as the most appropriate investigative tool to generate new concepts within the chosen context of serious games in dental education during the COVID-19 pandemic. The synthesis of literature addressing emerging topics is suitable for this type of review, with a view to constructing a new framework as an initial conceptualisation [21]. An integrative approach starts from (1) conceptually structuring the organisation of the review, (2) designing how to conduct it, and (3) writing up the outcome of the review through both critical analysis and synthesis of the literature [21]. The methodological search process was piloted and adjusted repetitively before performing the final search [22]. This rigorous method aimed to ensure the thoroughness of the review, in order to answer the following questions:

1. What is the trend in the current use of serious games in dental education?
2. What strengths of serious games make them suitable to be used during the COVID-19 pandemic?
3. How can a conceptual framework displaying the strengths of serious games emerge from this review?

3.1. Search Strategy

To assure that as much available evidence was identified as possible, the literature search was conducted across seven databases, covering areas of education, technology, and healthcare, including the Educational Resource Information Centre (ERIC), Web of Science, Scopus, Embase, Medline, ProQuest Dissertations & Theses Global, and Cochrane Central Register of Controlled Trials. In addition, Google Scholar and the reference lists of identified articles were explored to search for relevant papers. Grey literature was also screened to enable serious games used in dental education to be identified wherever possible. Search terms and Boolean combinations were implemented to identify relevant literature, which included 'Serious game', 'Computer-based game', 'Digital game', 'Video game' and 'Online game', together with 'Dental education', 'Dental student' and 'Dentistry'. The last search was conducted on 31 January 2021.

3.2. Inclusion and Exclusion Criteria

All types of empirical study of the use of serious games in dental education published between 2000 and 2021 were included in this review; however, they were excluded if they were not relevant to computer-based serious games and if they were not designed for educating and training dental learners. They were not included if they were not available in English or in full-text.

3.3. Literature Identified from the Search

The initial search across seven databases identified 120 articles. In addition, three further studies were identified through Google Scholar and the reference lists of identified articles. After removal of 18 duplicates, the titles and abstracts of 102 papers were reviewed. Eighty-two articles did not meet the inclusion criteria because they were not empirical studies and/or not relevant to serious games for dental students or professionals. Twenty full-text articles were accessed, of which a further five were excluded: one was not available in English; one was not relevant to dental education; and three were studies regarding non-serious games. Consequently, after consideration of inclusion and exclusion criteria, a total of 15 articles were included. This process is presented in Figure 1.

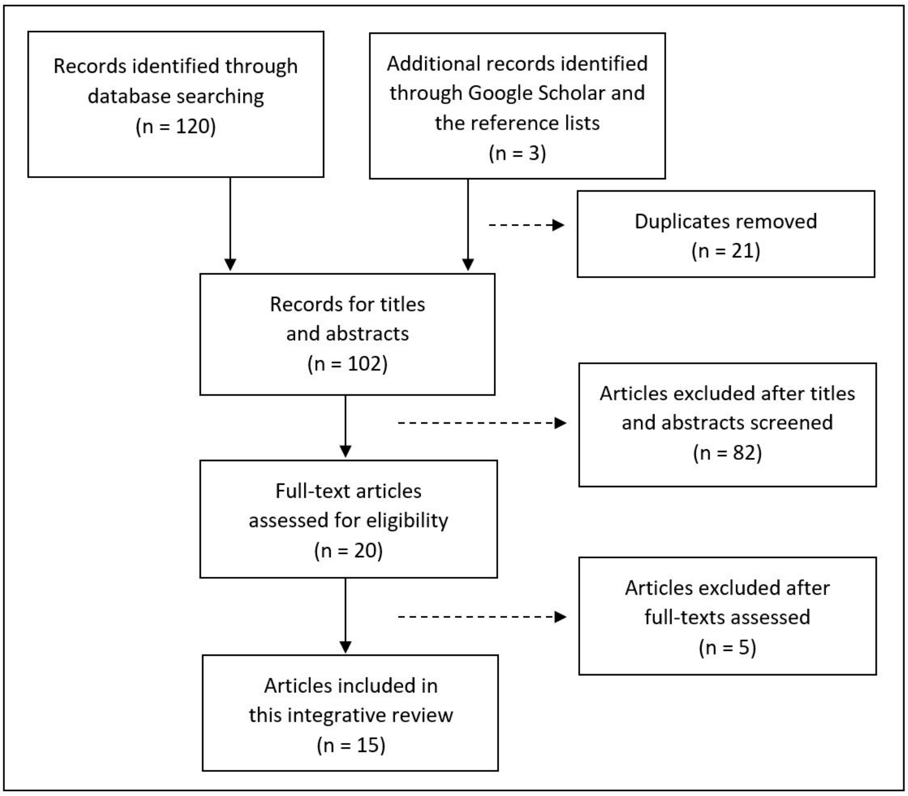

Figure 1. The articles selection process for the integrative review.

4. Results

4.1. Characteristics of Included Articles and Serious Games

The fifteen articles included in this review comprised seven journal articles [23–29], three conference papers [30–32], four book chapters [33–36], and one master's thesis [37], including 11 serious games in dental education. Three serious games (reported in four articles) were designed for pre-clinical dentistry with a focus on tooth morphology in 2014 and 2017 [30,37], histology in 2019 [28], and skull anatomy in 2020 [36]. Eleven articles were relevant to clinical dentistry, including dentin bonding for operative dentistry in 2011 [23], alginate mixing in 2013 [24], diagnosis and treatment planning in virtual dental patients in 2013 [33], dental public health in 2013, 2016 and 2017 [25,26,34], biosafety in 2018 and 2019 [27,35], dental anesthesia in 2019 [31], diagnosis in virtual endodontic patients in 2019 [32], and clinical skill assessment in 2020 [29]. These serious games and their details are presented in Table 1.

Following synthesis of the relevant literature the following themes emerged: educational outcomes, engagement and motivation, asynchronous distance learning, safe learning environment, and assessment issues. These five themes were considered as the key attributes of serious game use during the COVID-19 pandemic in a remote or distance learning context. Table 2 presents frequencies of the themes as reported in the included articles.

Table 1. Table presenting the 11 serious games shortlisted for the review.

Topics and Names (When Provided) of Serious Games	Year	Aims of Serious Games	Learning Activities within Serious Games	Outcomes of Serious Games
1. Dentin bonding [23]	2011	To enhance knowledge in applying a three-step resin bonding system.	To perform the virtual procedure through the sequencing steps in applying dentin bonding.	The game could improve knowledge and skills with no difference to the control group. Students' satisfaction with the game.
2. Alginate mixing, *Skills-O-Mat* [24]	2013	To improve knowledge and skills in alginate mixing.	To improve skills in mixing alginate following a virtual instructor, with immediate feedback on a computer screen.	Student self-perceptions of their skills were increased after the game completion and achievement was higher than in the traditional approach.
3. Diagnosis and treatment plan [33]	2013	To enhance competence in diagnosis and treatment plan of dental patients.	To collect information on patients and then to make a decision on options of diagnosis and treatment plan.	No evaluation of serious game outcomes.
4. Dental public health, *GRAPHIC* [25,26,34]	2017	To enhance competence in how to design oral health promotion at a community-based level.	To select the best five options of health promotion programs to improve oral health of population in a virtual town.	The game could improve knowledge; the log system allowed instructors to assess students without interrupting the learning process.
5. Tooth morphology [30,37]	2014 2017	To enhance knowledge in tooth morphology.	To place virtual teeth in their correct positions in lower jaw, using autostereoscopy and Natural User Interfaces.	The game could improve student knowledge, and it was also perceived positively as entertaining.
6. Biosafety, *Biosafety in dentistry* [27,35]	2018 2019	To enhance knowledge about risk control and prevention in dental services.	To act as a chosen game character responding to provided questions, in a quiz-like game format.	No evaluation of serious game outcomes.
7. Histology [28]	2019	To enhance knowledge in medical and dental histology.	To interact with histology-related multiple-choice quizzes through Kahoot® (a web-based gamification platform).	Student satisfaction with the game in learning about histology.
8. Dental anaesthesia, *VIDA Odonto* [31]	2019	To guide students to conduct dental anaesthesia with an ideal trajectory.	To perform an anaesthesia technique in a virtual patient using VR haptic device.	No evaluation of serious game outcomes.
9. Diagnosis in endodontic patients, *RealTeeth* [32]	2019	To improve competence in diagnosis of endodontics.	To act as a new dental graduate who is required to diagnose ten endodontic patients in a job application.	The game was perceived as an interesting learning tool to bridge the gap between theory and practice, but gaming elements should be further developed to improve engagement and motivation.
10. Skull anatomy, *Visualisation Studio Sim* [36]	2020	To enhance knowledge in skull anatomy.	To interact with 3D models of skull anatomy with rotation and zoom functions and then decide whether the presented skull is correct or not.	No evaluation of serious game outcomes.
11. Clinical skill assessment, *OSCEGame* [29]	2020	To prepare students for an OSCE (Objective Structured Clinical Examinations).	To act as a student taking an OSCE in a virtual environment.	The game supported students in improving time management skills and reducing OSCE-related anxiety.

Table 2. A table presenting frequencies of themes as reported in the included articles.

Strengths of Serious Games	Number of Serious Games Reported to Support Each Outcome
Positive educational outcomes	7
Engagement and motivation	7
Interactive asynchronous remote/distance learning	7
Safe learning environment	4
Stealth assessment	1

4.2. Educational Outcomes of Serious Games

Educational outcomes were reported in seven out of eleven serious games [23,24,28–30,32,34]. All of them were found to have positive impact on knowledge improvement with only three of them (discussing dentine bonding, tooth morphology, and dental public health) were evaluated using pre- and post-tests to assess competence of students before and after the use of serious games [23,30,34]. One article compared the effectiveness of serious games to traditional approaches and found no statistical difference [24].

Six serious games were measured using user perceptions in either quantitative or qualitative format and were perceived positively as effective learning tools [23,24,28–30,32]. For instance, most students reported that the 'OSCEGame' (Objective Structured Clinical Examinations) could increase time management skills and reduce anxiety, which could prepare them well for further examinations [29]. Students also felt more confident after completing the games [23,28]. Therefore, serious games seemed to have a positive educational impact in dental education.

4.3. Engagement and Motivation

Engagement and motivation seem to be another key theme emerging when evaluating serious games. Seven serious games were surveyed to gather user perceptions towards entertaining components [23,24,28,30,32,34,36], which were positively perceived by dental students as engaging learning tools. The application of game rules within serious games can make learning activities more engaging. For instance, a challenge can motivate and engage users in completing a game task; however, there should be a balance between challenges and player skills. It might have been difficult for students to be engaged with learning content if they needed to repetitively perform a game task [36].

Entertainment features of video games could also be embedded for enhancement of learning engagement and motivation included having a colourful interface and using interactive music [24,26]. Technologies can also make serious games more engaging. For example, autostereoscopy and natural user interfaces can be implemented to enhance sensation and interactivity, enabling dental students to interact with three-dimensional objects using their gestures [30]. A high-quality graphic could also be used to enhance visualisation for engagement in a new generation of learners (Figure 2), in addition to pedagogical impact [36]. The enhancement of engagement and motivation can be considered as a key strength of serious games over traditional learning approaches.

Figure 2. A screenshot from the skull anatomy game presenting an engaging graphic, reproduced with permission from Dall, R.

4.4. Serious Games as Interactive Asynchronous Distance Learning Environments

Seven of the eleven identified serious games in dental education enabled learning activities to be conducted online [23,25–29,32–36]. With these online serious games, asynchronous distance learning can be considered as an important strength in this COVID-19 pandemic. Distance learning allows dental students to learn to minimise the risk of COVID-19 infection. Together with asynchronous learning, students can learn in convenient time at a suitable pace [38]. Although the OSCEGame had set a limited time for students to complete each station, they could repetitively play the game until they felt confident about the examination [29]. Therefore, with serious games, each student can spend time differently in each section of the game and overall, based on their readiness.

There were three serious games requiring onsite settings to ensure learners had access to relevant materials [24,30,31,37]. Skills-O-Mat required a spoon attached to an accelerometer to capture how well students could mix alginate [24]. A serious game for dental anaesthesia implemented a haptic device for training students in conducting an anaesthetic procedure (Figure 3) [31]. Motion sensors seem to be important technologies for serious games in training psychomotor skills in dental education. According to a serious game for tooth morphology [30,37], although its learning outcomes were not psychomotor skills, auto-stereoscopy and natural user interfaces were implemented to enhance the interactivity of the game.

Instant feedback and immediate response appeared to be available in all included serious games in either formative or summative format [23,24,26–33,36]. The formative feedback allowed students to learn from their mistake [23,26], enabling them to improve their knowledge and skills. It appeared that informative feedback could be made more suitable, rather than being offered only in a numeric format [26]. The summative feedback would report how well students performed in a game task [24,32,36]; however, it could provide information on errors as a further improvement.

Figure 3. A user conducting a dental anaesthetic procedure using a haptic device [31], reproduced with permission from Nunes, F.L.S.

4.5. A Safe Learning Environment within Serious Games

Serious games can simulate a learning environment where students can experience dental practice safely. Dental students could be exposed to simulated patients in serious games, instead of 'real' clinical settings, to initially develop competences in oral diagnosis and treatment planning [32,33], as well as in local anaesthesia of the maxillofacial region [31]. This could minimise the risk of COVID-19 infection, whilst developing their skills in preparation for further training in clinical settings when possible.

In terms of community-based dentistry, serious games can simulate a learning situation where students can operate in a safe environment. GRAPHIC, (Games Research Applied to Public Health with Innovative Collaboration), a serious game for dental public health education, allowed students to gain disciplinary practice experience in a virtual town [26,34]. Within the game, students were firstly allowed to explore information on the virtual town provided by the system (Figure 4); they were then required to select the best five health promotion programmes, considering information about the town and research evidence, in order to improve the oral health of the population. This opportunity allows dental students to conduct community-based practice without being exposed to risk in a real community, and thus the risk of COVID-19 infection can be minimised.

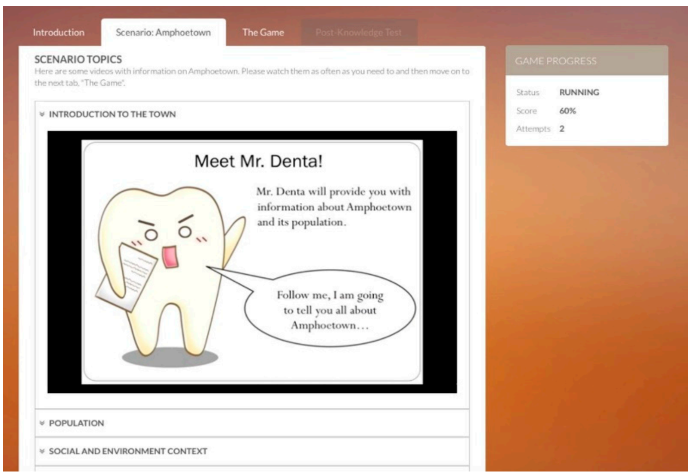

Figure 4. A screenshot of GRAPHIC (Games Research Applied to Public Health with Innovative Collaboration), where information on a virtual town is provided [34], reproduced with permission from Springer Nature.

4.6. Stealth Assessment in Serious Games

Stealth assessment, i.e., an approach to performance-based assessments that embeds assessments within digital games in order to measure how students are progressing toward targeted goals [7], can be considered as another strength when applied to serious games. The GRAPHIC system could record how students interacted with the game, and therefore dental instructors could assess logs of their performance and behaviours when performing the game task from the activity log data [26]. Designing stealth assessment in GRAPHIC also allowed students who did not progress to be identified, and therefore they could get additional support from academic staff for the achievement of their learning outcomes.

5. Discussion

5.1. Trends in Serious Game Use in Dental Education

This integrative review found an increasing use of serious games in dental education. There have been seven serious game papers published since 2018 [27–29,31,32,35,36], compared with eight between 2011 and 2017 [23–26,30,33,34,37]. This trend was similar to the use of serious games in general areas of education [39], including other healthcare education areas [11]. A rise in development of serious games may result from the increase of user demand, given that digitally-savvy generations are increasingly participants in all levels of education. In addition, game development software, together with increasingly advanced technologies, have become more affordable in recent years.

5.2. Potential in the Use of Serious Games in the COVID-19 Pandemic

Based on the articles reviewed, it appears that serious games should be supported for use as effective learning tools in dental education during the COVID-19 crisis, where distance learning is required to minimise the risk of COVID-19 infection. Given the time that it takes to complete research and move through publication, it may be that staff took the opportunity during the slowdown to ensure their findings were reported at that time, in support of their potential use. This development could be explained by the key strengths of serious games, which are (1) positive educational outcomes, (2) engagement and motivation, (3) asynchronous distance learning, (4) provision of a safe learning environment, and (5) assessment. These themes are discussed in this section to identify how they can support the use of serious games during the pandemic. The value of the development of a conceptual framework is that it allows further understanding of the key strengths of serious games, whether their effectiveness is evaluated during a pandemic or not.

5.2.1. Positive Educational Impact

Serious games can be considered as effective learning tools in terms of educational outcomes, as seen from the results of this review. Serious games have a positive impact on knowledge improvement amongst dental students, as there has been an increase of scores evaluated by pre- and post-assessments [23,30,34]. This outcome is broadly similar to serious games for other healthcare education areas [11,40]. In addition, most articles included in this review requested dental students to rate their perceptions of serious games [23,24,28–30,36]; the games were perceived by students as 'helpful' TEL tools in improving competence and preparing them for further studies.

In terms of learning design, serious games adapt a game concept to a learning process. According to the game cycle, introduced by Garris et al. [14], there are three components: 'user judgements', 'user behaviour', and 'system feedback'. In other words, when users preform an action in a game, the system should provide feedback for them to adapt their strategies to complete the game task, the so-called 'role of failure' [6]. Within serious games, a 'failure' is not a true 'failure', as it will enable learners to improve their knowledge and skills until they can complete a game task. Experiential learning can also be achieved while using serious games, allowing students to gain knowledge and skills through direct experience within games [41,42].

When comparing the effectiveness of serious games in terms of knowledge improvement, there seems to be no clear evidence in supporting them over other learning approaches. Only one article in this review compared the gaming approach with a passive format but found no statistical difference in terms of knowledge improvement [24]. The systematic review of serious games in healthcare education also reported similar findings, where the effectiveness of serious games over other learning approaches could not be sufficiently evident [40]. Consequently, it seems that serious games should be considered as a very helpful replacement of face-to-face learning formats during this pandemic, as they can provide positive educational outcomes at least as effectively as other learning approaches.

5.2.2. Engagement and Motivation

Engagement and motivation appear to be key strengths of serious games over other educational technology tools. Based on the results of this review, serious games were perceived positively as engaging learning strategies [23,24,28,30,34,36]. Although serious games are designed mainly for educational purposes, entertainment components are still required to engage and motivate learners. According to the game cycle [14], users need to perform a game task repetitively, failing and receiving feedback until they can complete the game. Therefore, if a serious game is not sufficiently engaging and motivating, students may cease the game, before achieving any learning outcomes.

The implementation of gaming technologies such as immersive graphics, gesture or motion control, voice recognition, and auto-stereoscopy appears to enhance serious games by making them more engaging. In the review, visual and audio aspects were reported to make the serious games more engaging. Both sounds and graphics can be considered as the entertainment components of serious games [43], and appear to play a fundamental role in engaging users [44]. Advanced technologies may also be used to enhance the entertainment value of serious games. Based on the included articles, interactivity can be designed using auto-stereoscopy and natural user interfaces to make the game more engaging [30]. This aspect can be considered as important, as this new generation of students in dental schools are familiar with video games, from an early age, and therefore serious games designed with very basic technologies might not be engaging for them.

Game rules and challenges can have an impact on the engagement with and motivation provided by serious games. One included article pointed out that a problem with engagement could occur if too many attempts were required for the same task [36]. This is an issue explained by the flow theory, where appropriate balance between competencies and challenges enhances flow of activities [45], which can be applied to game design [46–48]. In other words, if a game task is too simple, it could be boring. On the other hand, if it is too challenging, users may feel frustrated and stop playing the game. However, a serious game may be designed at different levels to allow learners to select a challenge that is suitable to their level of competence and knowledge.

5.2.3. Interactive Asynchronous Distance Learning

Of the eleven identified serious dental games, seven had already been using an online format [23,25–29,32–36]. Using an asynchronous format, these games allowed students to conduct their learning at a convenient time and suitable pace. Students with high knowledge and skills may progress through the game sooner than ones who require further improvement of competencies, in a personalised learning set up. Four of the serious games required students to conduct learning activities onsite [24,30,31,37], as they required specific equipment to capture the motions of students. However, they had the potential to be used in a distance learning setting, as these motion sensors appear to be affordable everyday equipment, such as smartphones, smartwatches, and game consoles.

Interactive asynchronous learning appears to take place in serious games, which can be considered as a unique strength for their use during the COVID-19 pandemic. As face-to-face sessions are constrained, online synchronous learning has gained more attention, and there is a real-time interactivity between instructors and students, where instant feedback can be provided [15,16]. On the other hand, immediate response and instant feedback may not be provided in asynchronous learning [17,18]. However, this integrative review has shown that immediate feedback (formative or summative) could be provided within all the serious games we included in the review [23,24,26–33,36], and therefore an interactive learning environment can be embedded in distance educational settings. These arguments support the use of serious games as interactive asynchronous distance learning environments in the COVID-19 crisis.

5.2.4. Safe Learning Environment

As outlined above, serious games can simulate a learning situation, enabling dental students to gain experiences in a safe learning environment. This review identified serious games used for experiencing clinical practice in supporting cognitive [32,33] and psychomotor skills [31]. Not only is there no harm to patients, but any mistakes in the game may increase the awareness of each student in clinical practice. This strength of serious games has also been found in other healthcare areas including medical and nursing education [11]. A serious game for dental public health education allowed dental students to be exposed in a virtual town, where they could gain experience of community-based practice in a safe environment [26,34]. Such simulated environments ensure harm reduction when learning dental treatments as well as oral health prevention and promotion, and also remove the actual infection risk of COVID-19.

5.2.5. Stealth Assessment

Stealth assessment was discussed in one of the identified articles in the context of using log data analytics in a serious game to indirectly observe how students interact with the game [26]. Serious game analytics combining gaming and learning analytics seem to be an important feature for the improvement of a game [49]. Serious game analytics can capture user-generated data (by creating an activity log of interaction between users and a game system), which are valuable for game developers or educators to identify areas for improvement as well as to assess performance of learners. Stealth assessment can also determine how students are progressing toward targeted goals [7]. It was included in this review as it represents an important learning design element in capturing the performance and improvement of learners when progressing towards the expected learning outcomes of serious games.

With stealth assessment, the flow of serious games can be maintained, so students can be engaged in the learning activities without self-consciousness and time pressures [50]. Therefore, the actual behaviour of students can be evaluated through serious game analytics when capturing their activities in completing a game task. Stealth assessment is not beneficial specifically to the COVID-19 context, but it represents another unique trait of serious games.

5.3. A Conceptual Framework of Serious Games' Strengths in the COVID-19 Pandemic

Our review indicates that serious games have a positive educational impact in dental education, whereby learners can learn from their failure. Engagement and motivation can be considered as important as the learning activities themselves, since students need to be engaged with serious gaming activities to achieve learning outcomes. Immediate and interactive feedback within a serious game can also enhance an asynchronous distance learning environment, which is considered necessary in this COVID-19 pandemic. Log systems enable stealth assessment, where gaming activities of students can be recorded, allowing instructors to assess performance without interrupting the learning process. In addition, serious games can simulate learning in situations where face to face participation is not possible, for instance, allowing students to interact with virtual patients or communities to improve competencies in a safe environment. These key strengths of serious games work together in supporting dental students to achieve learning outcomes during the pandemic or in other situations when there are restrictions in engaging with face-to-face learning.

Figure 5 presents the key elements of the conceptual framework. It defines the relevant variables of our review and maps out how they relate to each other. In the Figure, strengths in boxes with a thicker border are the ones reported in most studies; positive educational impact, enhanced engagement and motivation, and interactive synchronous learning environment were considered in seven serious games, safe learning environment was discussed in four, whilst stealth assessment was reported in one serious game (Table 2). The strengths include traits that are specifically designed for educational purposes; however, entertainment features are still required to engage and motivate users to repetitively perform a game task [5,14]. The arrows represent properties of the strengths; solid arrows represent essential properties that support the learning process and dash arrows represent desirable aspects that can enhance learning design.

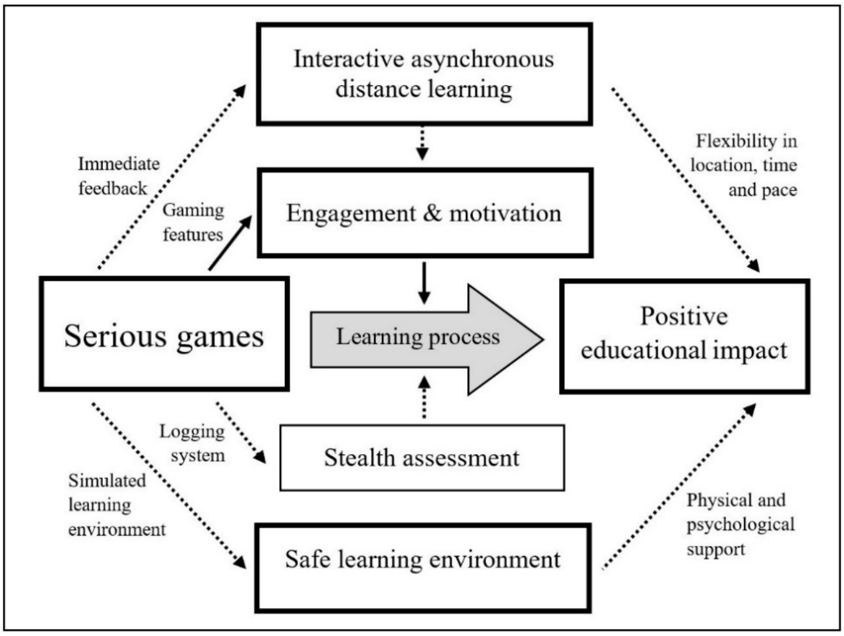

Figure 5. A conceptual framework of key strengths of serious games in the COVID-19 pandemic.

5.4. Limitations of this Review

There appears to be an increase in the use of serious games in dental education reported over the past two years since the last review we completed [11]; however, no research on serious dental games during the COVID-19 pandemic was identified. Consequently, it did not seem possible to evaluate the effectiveness of serious games for use in the pandemic crisis in dental education. In addition, although several serious dental games included in this review were designed as being available in an online format, none of the developers provided access to the games. Therefore, their descriptions were based only on the information provided in the included articles.

5.5. Implications for Future Research

This review has indicated the advantages of using serious games in dental education in extraordinary circumstances such as the COVID-19 pandemic. Further studies with robust methods, such as randomised control trials, are required to evaluate the effectiveness of serious games, compared with other learning approaches. In addition, future research should seek knowledge regarding the implementation of serious games in dental education both in normal and extraordinary circumstances such as in a pandemic crisis or a natural disaster. The conceptual framework presented in Figure 5 provides the basis of a useful tool to inform such research across all educational domains as innovations in TEL accelerate during and post-pandemic.

6. Conclusions

This integrative review revealed an increasing use of serious games since 2018. Our findings support the use of serious games in dental education during the COVID-19 pandemic and beyond, when and where the adoption of distance learning and teaching is necessary to minimise the infection risk. The conceptual framework derived from this integrative review combines the key supportive features of dental serious games i.e., (1) positive educational outcomes, (2) student engagement and enhanced learner motivation, the provision of (3) an interactive asynchronous distance learning, (4) safe learning environment, and (5) stealth assessment. The new normal for dental education forced by the COVID-19 crisis, consequently, appears to provide new opportunities for the use of serious games in dental education. However, future research should seek to employ robust methods to evaluate the effectiveness of serious games, in order to support learning strategies and their implementation in dental education.

Author Contributions: Conceptualization, K.S., P.A.R., S.H., and J.E.G.; methodology, K.S., P.A.R., S.H., and J.E.G.; validation, K.S., P.A.R., S.H., and J.E.G.; formal analysis, K.S.; investigation, K.S.; resources, K.S., P.A.R., S.H., and J.E.G.; Data Curation, K.S.; writing—original draft preparation, K.S.; writing—review & editing, P.A.R., S.H., and J.E.G.; visualization, K.S., P.A.R., S.H., and J.E.G.; supervision, P.A.R., S.H., and J.E.G. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data summarised in Table 1 of this review were analysed from 15 articles listed in the reference section [23–37].

Conflicts of Interest: The authors declare no conflict of interest.

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ISBN 978-3-0365-3809-9