education sciences

Trends on Educational Gamification

Challenges and Learning Opportunities

Edited by
José Carlos Piñero Charlo, María Teresa Costado Dios,
Enrique Carmona Medeiro and Fernando Lloret

Printed Edition of the Special Issue Published in *Education Sciences*

www.mdpi.com/journal/education

MDPI

Trends on Educational Gamification: Challenges and Learning Opportunities

Trends on Educational Gamification: Challenges and Learning Opportunities

Editors

José Carlos Piñero Charlo
María Teresa Costado Dios
Enrique Carmona Medeiro
Fernando Lloret

MDPI • Basel • Beijing • Wuhan • Barcelona • Belgrade • Manchester • Tokyo • Cluj • Tianjin

Editors
José Carlos Piñero Charlo
University of Cadiz
Spain

María Teresa Costado Dios
University of Cadiz
Spain

Enrique Carmona Medeiro
University of Cadiz
Spain

Fernando Lloret
University of Cadiz
Spain

Editorial Office
MDPI
St. Alban-Anlage 66
4052 Basel, Switzerland

This is a reprint of articles from the Special Issue published online in the open access journal *Education Sciences* (ISSN 2227-7102) (available at: https://www.mdpi.com/journal/education/special_issues/Trends_Educational_Gamification).

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 978-3-0365-3540-1 (Hbk)
ISBN 978-3-0365-3539-5 (PDF)

Contents

About the Editors

José Carlos Piñero Charlo has a degree in physics, mastery in science and technology of materials and a doctorate in physics. He worked as researcher at the Institut Néel (Grenoble, France) and at EPFL (Lausanne, Switzerland). Lecturer in didactic of the mathematics. Assistant professor in the department of didactic (section of mathematics). Research interest: educational gamification for learning mathematics. Professional interest in flipped and blended learning, experimented in the use of new technologies for teamgroup learning in university education. Expertise in educational gamification, assessment and mathematic teacher's professional knowledge. Professional researcher with a wide experience in electron microscopy techniques (both, scanning and transmission). Deep knowledge in physics, highlighting elecronics and quantum optics. Experimented in designing laboratory equipment.

María Teresa Costado Dios has a degree in mathematics from the University of Santiago de Compotela, mastery in physics of the cosmos and a doctorate in astrophysics from the University of La Laguna and the Canary Astrophysics Institute. She is a professional researcher with a wide experience in stellar clusters and star-forming regions, optical and infrared photometry, and radial velocity data.

Now she works as an assistant professor of didactic department (section of mathematics) at the University of Cádiz. She has teaching experience in mathematic knowledge and its didactic, with research interest in the active learning and instruction in university education, mathematic teacher's professional knowledge, and the affective domain of mathematics.

Enrique Carmona Medeiro has a degree in Physics (University of Córdoba, Spain), mastery in Research in the teaching and learning of Mathematics (International University of Andalusia, Spain), doctoral student in Didactics of Mathematics (University of Huelva, Spain), professor of Didactics of Mathematics and member of the research group Professional Development of Teachers (HUM-462) of the University of Cádiz. Research interests: Mathematics Education, Professional Development, Game-Based Learning.

Fernando Lloret has a degree in Physics from the University of Seville and a M.Sc. from the University of Cádiz (Spain). He worked as researcher at the Greek Foundation for Research and Technologies. He has a PhD in physics from the University of Grenoble Alps (France) and in Sciences from the University of Cádiz (Spain). After a post-doctoral stage at IMEC labs in Hasselt University (Belgium), he now works as an associate professor at the University of Cádiz. He has teaching experience in materials science, solid state physics, biophysics and applied physics. In addition to being part of international research projects, he is the co-organizer of various scientific dissemination projects.

Preface to "Trends on Educational Gamification: Challenges and Learning Opportunities"

Games are a natural activity—we all know how to play. Perhaps this is the key feature that explains the increase in the use of game-based learning (GBL) strategies: Applying games to education converts education into a universal activity.

Over the last ten years, the way in which education and training is delivered has considerably changed, not only due to a new technologic environment—plenty of social networks, MOOCs, etc.—but also because of the appearance of new methodologies. Such new methodologies are shifting the center of gravity: from the teacher to the student, with the aim of awakening relational aspects, as well as promoting imagination and divergent thinking. One new approach that holds considerable promise for helping to engage learners is, indeed, game-based learning (GBL).

However, while a growing number of institutions are beginning to see the validity of GBL, there are still many challenges to overcome before this type of learning can become widespread. Among these challenges, we find: (i) combining engaging game design with learning objectives and curriculum; (ii) evidencing learning outcomes; (iii) creating a gaming atmosphere that is adapted to all learners'ability; (iv) the specific knowledge required for a proper game design; (v) the cultural barriers with faculty and costs associated with developing a learning game.

In this Special Issue, we want to gather several studies and experiences in GBL to be shared with other teachers and researchers. The topics of this Special Issue will relate to the use of game-based learning strategies at all academic levels:

- Learning and instructional theory for game-based learning;
- Future of game-based learning;
- Social and collaborative aspects of game-based learning;
- Assessment in game-based learning;
- Case studies and best practices in the use of game-based learning;
- Evidences of learning processes in game-based experiences.

José Carlos Piñero Charlo, María Teresa Costado Dios, Enrique Carmona Medeiro, Fernando Lloret

Editors

education sciences

MDPI

Editorial

Preface for the Special Issue "Trends in Educational Gamification: Challenges and Learning Opportunities"

José Carlos Piñero Charlo [1,*], Nadja Belova [2], Eduardo Quevedo Gutiérrez [3], Alberto Zapatera Llinares [4], Elena Arboleya-García [5], Jakub Swacha [6], Paula López-Serentill [7] and Enrique Carmona-Medeiro [1]

1 Department of Didactics of Mathematics, Faculty of Educational Sciences, University of Cadiz, 11510 Cádiz, Spain; enrique.carmona@uca.es
2 Department of Chemistry Education, University of Bremen, 28359 Bremen, Germany; n.belova@uni-bremen.de
3 Institute for Applied Microelectronics, Campus de Tafira, University of Las Palmas de Gran Canaria, 35017 Las Palmas de Gran Canaria, Spain; eduardo.quevedo@ulpgc.es
4 Department of Educational Sciences, University CEU Cardenal Herrera, 03203 Elche, Spain; alberto.zapatera@uchceu.es
5 Department of Educational Sciences, University of Oviedo, 33005 Oviedo, Spain; elenaarboleyagarcia@gmail.com
6 Institute of Management, University of Szczecin, Cukrowa 8, 71-004 Szczecin, Poland; jakub.swacha@usz.edu.pl
7 Department of Specific Didactics, University of Girona, 17080 Girona, Spain; paula.lopez@udg.edu
* Correspondence: josecarlos.pinero@gm.uca.es; Tel.: +34-660-584895

Citation: Piñero Charlo, J.C.; Belova, N.; Quevedo Gutiérrez, E.; Zapatera Llinares, A.; Arboleya-García, E.; Swacha, J.; López-Serentill, P.; Carmona-Medeiro, E. Preface for the Special Issue "Trends in Educational Gamification: Challenges and Learning Opportunities". *Educ. Sci.* **2022**, *12*, 179. https://doi.org/10.3390/educsci12030179

Received: 22 February 2022
Accepted: 24 February 2022
Published: 4 March 2022

1. Introduction

Readers of the journal *Education Sciences* probably agree that playing games comes naturally—we all know how to play some game—however, because of the complexity of gaming, it is almost exclusively limited to mammals with regard to all animals: almost 80% of mammals use some sort of game for learning. Specifically with regard to humans, ever since we achieved some degree of civilization, we have played games for its proposed intellectual challenge and its entertainment value. Currently, it is difficult to participate in progressive modern societies without encountering some form of game play. In fact, the commercial video gaming industry now surpasses the movie and music industries in sales around the world, and more money is spent on games than on the other two combined. Therefore, if we consider games to be a natural activity, then applying games to education converts education into a universal activity. This is the key feature behind the use of Game-Based Learning (GBL) strategies.

In this regard, over the last ten years, the way in which education and training is delivered has considerably changed not only due to a new technologic environment—plenty of social networks, MOOCs, etc.—but also because of the appearance of new methodologies. Such new methodologies are shifting the focus from the teacher to the student, with the aims of awakening relational aspects as well as promoting imagination and divergent thinking. One new approach that holds considerable promise in helping engage learners is, indeed, game-based learning (GBL). The interest in research on GBL approaches has been continuously growing in the last decade. Particularly, since 2013, gamification in education has become a vivid and quickly developing area of research, with hundreds of new relevant publications coming out every year [1,2].

Researchers have reported that educational gamification strategies are being successfully applied in a wide variety of academic domains and educational levels, such as in studying English as second Language in higher education [3], in integrating subjects [4] such as mathematics and programming [5], or in working on mathematical and scientific problems [6]. Particularly, the skills and procedures used in certain games [7] have meaningful similarities with those used to solve mathematical problems. On the other hand, GBL is also used to boost relational aspects, such as increasing motivation [8], or to promote engagement with specific topics [9].

Furthermore, game design involves didactic-professional knowledge [10], so its use can deliver profit to both students and teachers and can be used to develop professional skills in future teachers. However, since teachers have a conceptual misunderstanding of gamification and STEAM education, they report insecurity and a lack of training for engaging in such educational methodologies [11]. In this regard, while a growing number of institutions are beginning to see the validity of GBL, many challenges still need to be overcome before this type of learning can become widespread.

This Special Issue of *Education Sciences*, titled "Trends in Educational Gamification: Challenges and Learning Opportunities", was developed to illuminate the inner workings of immersive games. Therefore, the primary aim of this Special Issue was to provide a focus for people working on the abovementioned research frames by providing a platform on which reflections on how to move gamification studies a step forward can be compiled. We invited researchers to submit original research on the deployment of gamified systems embedding novel game elements as well as rigorous quantitative and qualitative user studies that may also explore theoretical reflections grounded in empirical results. We also encouraged the scientific community to submit research covering all academic levels (pre-K12 to university) as well as a variety of games: board games, videogames, and live-action games, among others.

The 11 articles presented in this Special Issue deal with a wide range of aspects in Educational Gamification. We organized the discussions in a comprehensive manner so that each specific contribution can be highlighted. In this regard, as the Lead Editor and coordinator of this Special Issue, I proposed a collaborative structure to write this preface, so that experts can contribute to each of sections. Collaborative writing is a process of producing a written work as a group where all team members contributed to the content and the decisions about how the group will function. Therefore, one of my tasks as the leading editor was to coordinate and communicate with the different team members (the authors of the publications in this Special Issue) and, thus, to assign the redaction of specific sections—fitting each author's expertise—to produce and deliver a proper analysis. Finally, I highlight that the opportunity to coordinate and participate in this Special Issue has served as a great stimulus to revisiting recently conducted works and has given me the chance to work with colleagues with whom I had never conceived of sharing the same floor. I am thankful to all of the contributors of this Special Issue, and I hope to cooperate with them again in the future.

José Piñero
Lead Editor and coordinator of the SI

2. The State-of-the-Art

Jakub Swacha

No scientific study should begin without first checking existing knowledge. This becomes challenging in areas undergoing rapid development, such as the one covered by this Special Issue: Educational Gamification, where the sheer amount of publications is overwhelming. In this context, a bibliometric survey is useful as it enables a researcher to consider thousands of publications within a reasonable time. This fast pace comes at a price: such a survey deals only with the most easily accessible data pertaining to each document, so in most cases, it is infeasible to answer detailed research questions. However, it is perfectly capable of answering general questions such as those regarding research topics, active researchers and research institutions, and their interconnections, which is often exactly what we need to grasp what is going on in that field of study.

In the bibliometric survey on Educational Gamification presented in [1], an exclusive approach was followed in an attempt to include only work that was highly relevant to the topic (i.e., preferring false negatives over false positives). At the cost of ignoring some relevant work, this approach allowed for papers of low relevance yet high visibility, such as highly cited papers on gamification or education but not on Educational Gamification, to be avoided and thus to not pollute the results.

As a researcher focused on just a narrow section of Educational Gamification, pertaining to teaching computer programming, I have found the work on the bibliometric survey both revealing and rewarding, especially as some of the results were far from expected. I hope that my paper provides readers with a good picture of the field before they delve into the details presented in the excellent papers forming the rest of this Special Issue.

3. Game Design

Eduardo Quevedo Gutiérrez and Alberto Zapatera Llinares

Game design (applied to education) is the art of applying design and aesthetics to create a game with formative and entertainment purposes. Increasingly, elements and principles of game design are also applied to other interactions in the form of gamification. Academically, game design is part of game studies, while game theory studies strategic decision making (primarily in non-game situations). Games have historically inspired seminal research in the fields of probability, artificial intelligence, economics, and optimization theory. Applying game design to itself is a current research topic in metadesign.

The game design process associated with a computer can extend its purposes to the considered programming language. Using a simple and accessible programming language such as Scratch (proposed in our contribution as a didactic tool to teach functions) favors redesign (in Scratch, this process is known as reinvention). This scheme promotes the Creative Learning Spiral based on five components: *Imagine*, *Create*, *Play*, *Share*, and *Reflect*. Therefore, the authors understand that the integration of computational thinking in the school curriculum, including gamification as a methodology to implement it, promotes creativity and helps students learn the basics of programming languages. In this scope, game design serves as a means to an end. In fact, the approach carried out in our contribution considering the learning of functions through programming with Scratch is a game in and of itself. It allows the student to try different options until a problem solution is reached without fear of making mistakes in the process. This is very interesting since not being able to reach a final solution may involve the student's motivation to continue playing and improving; on the contrary, in the education system, usually mistakes are penalized, which can lead to demotivation. The authors will continue researching this topic to promote student motivation.

4. Live-Action Games: Educational Escape Rooms

Nadja Belova

Whoever plays, steps out of everyday experience; in a sense, overrides it; and immerses themselves in a game world. This phenomenon is addressed in the concept of the "flow theory" [10]. Here, the state of "flow" is described as total absorption by a task that is both challenging and enjoyable. Such a totally immersive recent game trend is the so-called escape room. Escape rooms are a relatively new game concept that has been gaining popularity since around 2012 and can be considered a sort of hype in the science education community in the last five years. Educational Escape Rooms are a sort of live-action team-based game where players discover clues, solve puzzles, and accomplish tasks in one or more rooms in order to achieve a specific goal (usually escaping from the room) in a limited amount of time. To gain an overview of the state of science education research on this topic, we conducted a literature review. During the work in this review, subconsciously, the following questions always arose: Is this method really worth the hype? Are such immersive but also very elaborate methods really more effective—in terms of learning outcomes and competence development? As of now, it seems that the answer is that we do not know. We were able to identify not only some gaps in Educational Escape Room development (especially a need for scenarios that are easily adaptable to different educational settings) but also a major research gap when it comes to more empirical evidence on their actual effects. This is the area where research will definitely have to provide more results in the near future and to systematize the results because not all activities are automatically good even if everyone participates in it.

5. Board Games

Elena Arboleya-García

Some educators spotted that board games are under-utilized in education. Games can engage students with different learning styles and can inspire individual creativity. They create non-threatening environments through tangible elements, hands-on tasks, or mutual learning, where lower levels of knowledge and failed tasks can be turned into a meaningful-learning acquisition. However, interdisciplinarity is also needed. It offers students a better understanding of the teaching–learning processes, as they could be able to identify and connect information from the separate subjects of the school curriculum.

Based on these statements, we conceived 'The Game of The Sea' to bring marine environment and ocean knowledge closer to students. From our educative experiences, as students first and educators second, we noticed that, throughout the stages of primary and secondary education, science subjects (in particular, those related to biology) provide education that is not properly connected between each level. Therefore, students are not able to construct long-term memories about this specific topic. The design and implementation of 'The Game of The Sea' entails the creation of a network of knowledge from different levels and from different subjects (not only scientific ones) addressed in the school curriculum. Once this integrative knowledge was acquired, our students obtained a better awareness of marine environment and we could confirm that we contributed to teaching environmentally responsible citizens.

Board games and interdisciplinarity represent the missing tools in our toolboxes, in particular, with regard to secondary education. In contrast with primary education, games are usually not considered a common didactic tool by teachers in secondary education despite games providing the possibility of improving traditional lectures and their relationships with students. The research presented on this Special Issue introduces the background needed to incorporate games into school curricula and to encourage educators to embrace that possibility of adopting these tools.

6. STEAM Education

Paula López-Serentill

STEAM Education has recently become a trend in educational development that promotes learning throughout and for the interdisciplinary enterprise between Science, Technology, Engineering, the Arts, and Math. Teaching relevant, in-demand skills that will prepare students to become innovators in an ever-evolving world is paramount not only for the future of the students themselves but also for the future of the country. STEAM also empowers teachers to employ project-based learning that crosses each of the five disciplines and fosters an inclusive learning environment in which all students can engage and contribute. Within STEAM education, one useful tool is gamification, which is reported as a powerful tool for teachers at all levels in the educational system.

Our results show that a high percentage of math teachers think that this kind of activity has positive effects on students' development, improving their affective domain toward mathematics and required skills for mathematical competency. Notwithstanding, many teachers reported insecurity and a lack of knowledge, which is why we consider it necessary to promote STEAM training and, in particular, the use of gamification as another tool in the mathematics classroom.

7. Conclusions

During the last decades, we have witnessed the frenetic development of technologies, as well as the expansion and rise in the video game industry, board games, and escape rooms. The possibilities of innovating within the classroom using playful environments with didactic intentions have increased remarkably. The need for teachers to find new learning scenarios that align with the interests of students has led to the emergence and consolidation of two methodologies in the classroom based on the educational use of games: game-based learning and gamification. Therefore, a question emerges: How can the scientific community help these innovative movements really improve learning in the classroom?

The scientific community is responsible for exploring the educational potential of these new learning environments in depth and for providing empirical evidence on the educational possibilities they present. Although research on the educational use of games has produced results indicating that games can be healthy contributions to all educational areas, their possibilities have not yet been explored in depth. Regardless of the nature of the game (software, applications, video games, programming environments, board games, or escape rooms), more empirical evidence is required to reveal the added value of game-based learning situations compared with other types of learning. In this regard, we believe that more evidence may be of interest in progressing research on the educational use of games: especially studies on how these learning environments affect motivation and involvement, cooperation, creativity, and problem solving; studies on the different possibilities of use, specifically how they promote learning, how to practice and integrate what has been learned, how to problematize a situation, how to evaluate what has been learned, what causes triggering situations, etc.; studies that contribute to the systematization of principles for design and management; and studies on the design of disciplinary and interdisciplinary learning situations that are transferable to different educational levels, contexts, and training situations.

Finally, we believe that this Special Issue provides interesting key points that can help in understanding the effective use of educational games. In this Special Issue, the reader will find a varied and representative sample of current research issues related to the educational use of games from different disciplines, such as mathematics, music, English as second language, and marine biology, among others; to a diverse sample of games such as escape rooms, board games, and the Scratch programming environment; and to different methodological approaches, bibliometrics, bibliographic reviews, ethnographies, exploratory studies, case studies, etc.

Enrique Carmona Medeiro
Guest Editor of the SI

Author Contributions: Conceptualization, supervision, writing-original draft preparation, writing-review and editing, J.C.P.C.; writing-original draft preparation, writing-review and editing, N.B., E.Q.G., A.Z.L., E.A.-G., J.S., P.L.-S. and E.C.-M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding. Specific information is available on each manuscript that is included on this Special Issue.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data discussed on this manuscript are available on the website of the special issue: https://www.mdpi.com/journal/education/special_issues/Trends_Educational_Gamification, accessed on 21 February 2022.

Acknowledgments: The leading editor and coordinator of this special issue would like to thank to the research groups HUM462 (Teachers' professional development) and HUM634 (Experimental Educational Psychology Laboratory) as well as to the project "Mathematical cognition and ABN methodology in the 3rd stage of the primary education" (PID2019-105584GB-I00).

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

References

1. Swacha, J. State of Research on Gamification in Education: A Bibliometric Survey. *Educ. Sci.* **2021**, *11*, 69. [CrossRef]
2. Lathwesen, C.; Belova, N. Escape Rooms in STEM Teaching and Learning—Prospective Field or Declining Trend? A Literature Review. *Educ. Sci.* **2021**, *11*, 308. [CrossRef]
3. Hernández-Prados, M.; Belmonte, M.L.; Manzanares-Ruiz, J.C. How to Run Your Own Online Business: A Gamification Experience in ESL. *Educ. Sci.* **2021**, *11*, 697. [CrossRef]
4. Arboleya-García, E.; Miralles, L. 'The Game of the Sea': An Interdisciplinary Educational Board Game on the Marine Environment and Ocean Awareness for Primary and Secondary Students. *Educ. Sci.* **2022**, *12*, 57. [CrossRef]
5. Quevedo Gutiérrez, E.; Llinares, A.Z. Assessment of *Scratch* Programming Language as a Didactic Tool to Teach Functions. *Educ. Sci.* **2021**, *11*, 499. [CrossRef]
6. Fernández-Oliveras, A.; Espigares-Gámez, M.J.; Oliveras, M.L. Implementation of a Playful Microproject Based on Traditional Games for Working on Mathematical and Scientific Content. *Educ. Sci.* **2021**, *11*, 624. [CrossRef]
7. Antequera-Barroso, J.A.; Revuelta-Domínguez, F.-I.; Guerra Antequera, J. Similarities in Procedures Used to Solve Mathematical Problems and Video Games. *Educ. Sci.* **2022**, *12*, 172. [CrossRef]
8. Macías-Guillén, A.; Díez, R.M.; Serrano-Luján, L.; Borrás-Gené, O. Educational Hall Escape: Increasing Motivation and Raising Emotions in Higher Education Students. *Educ. Sci.* **2021**, *11*, 527. [CrossRef]
9. Vázquez-Vílchez, M.; Garrido-Rosales, D.; Pérez-Fernández, B.; Fernández-Oliveras, A. Using a Cooperative Educational Game to Promote Pro-Environmental Engagement in Future Teachers. *Educ. Sci.* **2021**, *11*, 691. [CrossRef]
10. Charlo, J.P.; García, P.O.; García, S.R. Formative Potential of the Development and Assessment of an Educational Escape Room Designed to Integrate Music-Mathematical Knowledge. *Educ. Sci.* **2021**, *11*, 131. [CrossRef]
11. López, P.; Rodrigues-Silva, J.; Alsina, Á. Brazilian and Spanish Mathematics Teachers' Predispositions towards Gamification in STEAM Education. *Educ. Sci.* **2021**, *11*, 618. [CrossRef]

education sciences

Article

State of Research on Gamification in Education: A Bibliometric Survey

Jakub Swacha

Institute of Management, University of Szczecin, Cukrowa 8, 71-004 Szczecin, Poland; jakub.swacha@usz.edu.pl

Abstract: Recent years have brought a rapid growth of scientific output in the area of gamification in education. In this paper, we try to identify its main characteristics using a bibliometric approach. Our preliminary analysis uses Google Scholar, Scopus, and Web of Science as data sources, whereas the main analysis is performed on 2517 records retrieved from Scopus. The results comprise the cross-coverage of databases, geographic distribution of research, forms of publication, addressed research areas and topics, preferred publishing venues, the most involved scientific institutions and researchers, collaboration among researchers, and research impact. The main conclusions underline the sustained growth of the research output in the area for at least seven years, the widespread interest in the area across countries and branches of science, and an effective research communication in the area documented by the number of citations and the map of co-citations.

Keywords: gamification; education; literature survey; publication analysis

Citation: Swacha, J. State of Research on Gamification in Education: A Bibliometric Survey. *Educ. Sci.* **2021**, *11*, 69. https://doi.org/10.3390/educsci11020069

Academic Editor: José Carlos Piñero Charlo

Received: 31 December 2020
Accepted: 4 February 2021
Published: 10 February 2021

1. Introduction

Since gamification rose to popularity in the early 2010s, it has become an object of interest for education researchers. A short but good explanation of this interest was provided by Karl M. Kapp, who not only called gamification "the ideal process for creating engaging learning environments" [1], but also defined it as "using game-based mechanics, aesthetics and game thinking to engage people, motivate action, promote learning, and solve problems" [1], implicitly pointing out its key virtue: the ability to build engagement and motivation.

Consequently, gamification has been applied at various levels of education (from preschool [2], through elementary [3], secondary [4], and higher [5], to adult education [6]), and to various subjects (including as diverse ones as anatomy and physiology [7], architecture [8], computer programming [9], chemistry [10], foreign language [4], mathematics [11], or organizational behavior [12]). Gamification models were designed [13], specialized frameworks developed [14], and dedicated tools implemented [15]. Both success stories [3] and failures [16] were reported.

In 2013, Simone de Sousa Borges et al. retrieved a total of 357 publications querying five bibliographic databases with the keyword "gamification" alone [17]. At the moment of writing these words, Google Scholar alone returns 19,000 results for the very same keyword. With such a flood of new knowledge, it becomes more and more difficult for a researcher to keep track of the state of gamification research even in his/her particular area of interest, such as education. This explains the demand for various kinds of literature surveys, providing a more or less comprehensive picture of the field. Searching for the keyword "literature" within the results of our main query on gamification in education (see Sections 2 and 3), we were able to identify 22 publications in this vein that employed a systematic approach to data collection and covered more than 10 publications. They are listed in Table 1. The Scope column defines the subdomain to which a given study was restricted, the Items column provides the number of publications that were eventually analyzed (after filtering out the ones considered irrelevant), the Databases column lists the data sources used (for the sake of brevity, dataset details were omitted), and the Year column specifies the last year covered in a given survey. The table is sorted upon the number of covered publications.

Table 1. Prior literature surveys in the area of gamification in education.

Reference	Scope	Items	Databases [1]	Year
[18]	Higher education	1029	WoS	2019
[19]	(unrestricted)	313	WoS	2018
[20]	Management	244	Scopus, WoS	2017
[21]	(unrestricted)	139	WoS	2014
[22]	Empirical research	128	Scopus	2015
[23]	(unrestricted)	119	Scholar, WoS, Scopus, ResearchGate, Academia	2014
[24]	(unrestricted)	95	EBSCO, ScienceDirect, AISeL	2018
[25]	Statistics	49	Scopus, AISeL	2019
[26]	Engineering	48	IEEE	2019
[27]	Tailored gamification	42	ACM, IEEE, ScienceDirect, Scopus, Springer	2019
[28]	Empirical research	41	ACM, IEEE, ScienceDirect, Scopus, ERIC, Scholar	2015
[29]	Higher education	41	ACM, EBSCO, ASME, IEEE, PsychINFO, Scopus	2017
[30]	Information Systems	41	AISeL, ACM	2016
[31]	Peer review	39	ACM, IEEE, ScienceDirect, Springer, Scopus, WoS, ERIC	2018
[32]	Empirical research	34	ACM, IEEE, ScienceDirect, Scopus, Springer, ERIC, Scholar	2014
[33]	MOOCs	34	ACM, IEEE, ScienceDirect, Scopus, Springer,	2017
[34]	Higher education/STEM	30	WoS	2016
[17]	(unrestricted)	26	ACM, ScienceDirect, IEEE, Scopus, Springer	2013
[35]	Empirical research	24	EBSCO, Proquest, WoS, Scopus, ScienceDirect, Scholar, ACM, AISeL	2013
[36]	Software engineering	21	ACM, IEEE, Scopus, ScienceDirect, WoS	2017
[37]	Adaptive gamification	20	ACM, IEEE, ScienceDirect, Springer, Scholar	2019
[38]	Computer Science	16	ACM, IEEE, ProQuest, Web of Science	2017

[1] ACM: ACM Digital Library; ASME: ASME Digital Collection; IEEE: IEEE Xplore; Scholar: Google Scholar; Springer: Springer Link; WoS: Web of Science.

Looking at the contents of Table 1, most of the listed surveys are focused on a specific education level [18,29,34], subject [20,25–27,30,31,33,34,36–38] or reported research type [22,28,32,35], with the remaining ones were either outdated [17,21,23] or using too restricted search criteria [19] and/or selection of sources [24] to achieve an adequate coverage of the state of research on gamification in education. We therefore identify a research gap in the lack of an up-to-date survey of the scientific output in this field, not restricted to its particular subdomain or type of research. The aim of this research is to satisfy this gap. Although we put our priority on wide coverage rather than deep coverage of the problem area, we consider our work as both a continuation and extension of the prior works listed in Table 1.

Considering the aim of the research, we state the following research questions:

RQ1. How has the scientific output with regard to gamification in education developed over time?

RQ2. Which countries contribute the most to the scientific output with regard to gamification in education?

RQ3. What publication types are mostly used to convey new research results with regard to gamification in education?

RQ4. In the context of which research areas and topics are the problems of gamification in education addressed?

RQ5. What are the publishing venues through which the results of gamification in education research are most often disseminated?

RQ6. Which scientific institutions are involved in the research on gamification in education?

RQ7. Who are the most prolific authors contributing to the research on gamification in education?

RQ8. Is there a wide collaboration among researchers of gamification in education?

RQ9. Are the results of gamification in education research widely acknowledged or do they only reach a small groups of followers?

In the following section, the methods and data sources used to answer the stated questions are described. The obtained results are presented in Section 3, and discussed in the final section.

2. Materials and Methods

In the context of both the stated research questions and the volume of data to be processed, we decided to apply the bibliometric approach to achieve our goal. Bibliometrics, according to Nicholas and Ritchie [39], is "the statistical or quantitative description of literature", with "literature" understood as "a group of related documents". The exemplary characteristics of literature that may be described are "subject, document form (. . .), language (. . .), date" [39]. Surveys based on the bibliometric approach have been proven feasible and effective in various research areas, including business studies [40], medicine [41], tourism research [42], and education sciences [43].

Three stages of the survey procedure have been defined:

1. Survey planning: Selection of data sources and specification of search criteria.
2. Preliminary analysis: Answering RQ1 and selecting the data source which provides the widest coverage of the scientific output with regard to gamification in education for further analysis.
3. Main analysis: Answering the remaining RQs.

The necessary planning of the survey consisted in the selection of data sources for preliminary analysis and specification of search criteria. All data sources listed in the Databases column of Table 1 were considered for inclusion in the survey. Eventually, three sources were selected: Scopus, Web of Science (Core Collection) and Google Scholar, for the following reasons:

- they index the largest number of documents, far exceeding the other databases;
- most of the content of commercial publisher databases (e.g., Springer Link and ScienceDirect) is indexed by at least one of the three selected data sources;
- most of the other databases used in prior research (e.g., ACM Digital Library; AISeL, ASME Digital Collection, IEEE Xplore) are dedicated to specific topic areas (such as computer science, information systems, or mechanical engineering), and this survey was not restricted to any of these areas;
- ERIC is a database dedicated to an area consistent with the scope of the survey (education); however, it does not provide citation data which automatically excludes its use in the main analysis stage. Note that a simple query for peer-reviewed publications on "education" and "gamification" resulted in 262 items, which, while a small fraction of the number of items retrieved from the other sources, makes it a source to consider in future literature surveys on gamification in education.

With the abundance of literature on the survey topic, we wanted more to avoid false positives in the search results rather than minimize the number of false negatives. Therefore, we decided to use just two keywords: "education" and "gamification". While we considered the inclusion of other terms, we abstained from doing so. In particular, "learning" was abandoned as denoting a wider concept than education, and "instruction" was abandoned as a term having multiple meanings, only one of them connected to education.

For the two bibliographic databases (Scopus and Web of Science), the following assumptions were taken into consideration:

- a paper relevant to gamification should have the term "gamification" mentioned in its title, keywords, or abstract;
- a paper relevant to education should either have the term "education" or "educational" mentioned in its title or keywords (we ignore abstracts here, as many papers on gamification in non-educational contexts mention education as an exemplary field of gamification in their abstracts), or be published in an educational context (in a journal, book, or proceedings of a conference dedicated to education).

The search was performed on a single day (29 December 2020). Having retrieved, respectively, 2820 items from Scopus and 1988 items from Web of Science, we defined additional constraints:

- papers from 2021 should be excluded (to avoid the false impression that the results cover the scientific output from 2021, whereas only few publications with such a publication date were found);
- papers not in English should be excluded (to avoid the false impression that the results cover scientific output in non-English languages, whereas only a small amount of such publications were found; a proper survey in this vein should include various national-level bibliographic databases);
- only the publications in the type of book, chapter, journal article, and conference paper should be included (to exclude all publications such as reviews, editorials, etc. that do not convey new research results).

Consequently, the following search terms were used:

- in Scopus: "(PUBYEAR < 2021) AND TITLE-ABS-KEY (gamification) AND (TITLE (education*) OR KEY (education*) OR CONFNAME (education*) OR SRCTITLE (education*)) AND (LIMIT-TO (DOCTYPE, "cp") OR LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "ch") OR LIMIT-TO (DOCTYPE, "bk")) AND (LIMIT-TO (LANGUAGE, "English"))",
- in Web of Science: "(((TI = gamification OR AK = gamification OR AB = gamification) AND (TI = education* OR AK = education* OR SO = education* OR CF = education*))) AND LANGUAGE: (English) AND DOCUMENT TYPES: (Article OR Book OR Book Chapter OR Proceedings Paper)", with the following additional search criteria: "Indexes = SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI Timespan = 1900–2020".

As a result, 2517 items from Scopus and 1743 items from Web of Science were retrieved.

The case of Google Scholar is different. First of all, we were not able to define search criteria that would strictly resemble the queries performed on the other two databases. This is a well-known problem in the bibliometric literature (see e.g., [44]). Trying to make the search criteria as similar as possible, we decided to use two keywords: "education" and "gamification" with the "allintitle" option. Note that the exact search procedure performed by Google Scholar is not known, but the reader should be aware that the mentioned option does not mean that among the 1040 documents retrieved using these criteria, there were only those exactly containing the given keywords in the title (in fact, many of them did not).

Then, additional constraints were added: patents were excluded and the maximum year of publication was set to 2020; it was also ensured that only English-language documents were retrieved. This resulted in the following search results link: "https://scholar.google.com/scholar?hl=pl&lr=lang_en&as_sdt=1%2C5&as_yhi=2020&q=allintitle%3Aeducation+gamification\T1\textquotedblright. A total of 980 items were retrieved with it.

3. Results

3.1. Preliminary Analysis

In order to address RQ1, first, the lists of publications retrieved from the three databases were combined using publication title and year as the matching key. Due to various notations of authors' names, we decided not to include them in the matching key, however as the chance of two same-year publications from two distinct authors having exactly the same title is low, the effect of this decision on the obtained results is negligible. Note however, that the omission of the other metadata in the matching key (for instance, the journal or book title) inflated the number of duplicates, as all publications having the same title and year are treated as one: while such a situation does not happen frequently, sometimes it does (e.g., a paper is published first in conference proceedings and later the same year in a post-conference book or as a journal article).

Moreover, as we were aware of notable differences in letter case and interpunction of titles obtained from respective databases, the titles were matched considering only the alphanumeric characters, all converted to lowercase. As a result, 3944 unique items were identified (out of 5240 total retrieved items).

Table 2 shows the cross-coverage between three queried databases (given in the first column). For every row, corresponding to database D, the three columns (referred to as C2..4) list the share of publications retrieved from D that were also found in the database given in the respective header of C2..4 (note the denominator is the number of publications in D, hence the total of respective columns is not 100%). If the column denotes database D, the given number is the share of publications from D that were not found in either of the two other databases. The fifth column gives the share of items having duplicates in the same database. It should be reminded that the number of duplicates reported here results from the chosen data consolidation procedure (see the previous paragraph), and includes as duplicates many papers which are not actually duplicates. On the other hand, while the mentioned procedure helped to remove many actual duplicates, particularly from the Google Scholar results, we have found through manual examination of randomly chosen items that there still were multiple publications listed under several more or less modified titles (usually fragments of other metadata were included in the actual title, probably as a result of an imperfect automatic acquisition of metadata by Google Scholar). As we did not aim to ensure the quality of bibliographic data, we did not attempt to correct such issues.

Table 2. Co-occurrence of publications in the considered databases.

Database	Google Scholar	Scopus	Web of Science	Duplicates	Coverage
Google Scholar	66.7%	10.2%	6.2%	16.8%	20.7%
Scopus	4.0%	62.3%	28.3%	5.4%	60.4%
Web of Science	3.5%	40.9%	48.7%	6.9%	41.1%

The values in columns C2..5 in each respective row sum up to 100%. The sixth column is not related directly to the preceding four, and shows the share of items retrieved from database D in the combined list of 3944 unique items.

Looking at the obtained results, it is quite surprising—in the context of prior results such as those reported in [45], which indicated similar coverage at least of Scopus and Web of Science—how large the share of publications unique to just one database is. Even if we look only at the two bibliographic databases which were searched using criteria as alike as possible, it reaches about half (Web of Science) or more than half (Scopus) of their respective content. This is an important observation for future literature surveys on the topic, indicating the significant differences in coverage of the databases.

Figure 1 provides a visual answer to RQ1, showing the number of publications registered in respective databases in subsequent years. The items with no publication year indicated were omitted, as well as few publications having erroneous metadata listing year of publication before 2010 (even as early as 1982) whereas their actual year of publication was found to be much later (after 2010).

Looking at Figure 1, the earliest items retrieved from Google Scholar were published in 2010, from Scopus in 2011, and in Web of Science in 2012. The scientific output became considerable in 2013 and grew from that year on. According to data from both Scopus and Web of Science, the growth dynamics was high and continued until recently. The results obtained from Google Scholar paint a somewhat different picture: here, the growth was moderate and reached its peak in 2018.

Regarding the data for 2020, it must be taken into consideration that although the survey was performed at the end of 2020, there are many publications still in press which will have a publication year of 2020 (this applies to all three data sources), and there is a delay between when an item is published and when it is registered in a bibliographic database. This applies specifically to Scopus and Web of Science (especially the latter, having very long data processing periods, which explains the sharp drop in the number of publications for 2020).

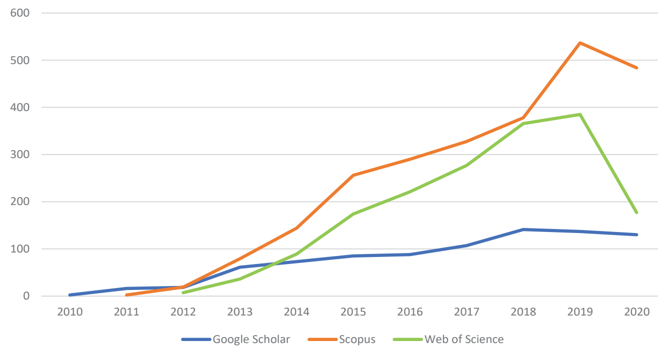


Figure 1. Number of publications meeting the search criteria in subsequent years.

For the purpose of performing the main analysis, the largest data source, Scopus, was chosen, as it covers a sufficient share (over 60%) of relevant publications identified in any of the considered databases and provides the complete set of information needed to answer all stated research questions. It is also the only source which provides unique author identification numbers, helping to avoid mistreatment of a single author publishing under different names or name forms as well as multiple authors having the same surname and first name initials. To illustrate the advantages of such precise identification of authors, among the 24 most prolific authors listed in Section 3.2.6, if the counts obtained by assigning publications to authors by their surname and initials were used instead, only 13 authors would have their publication count unchanged, of which only nine would retain their rank, and four authors would not even make it to the list.

3.2. Main Analysis

3.2.1. Geographic Distribution of Scientific Contribution

Figure 2 provides a visual answer to RQ2, showing the geographic distribution of the research based on data retrieved from Scopus regarding location of institutions with which the publication authors were affiliated. Researchers from exactly 100 countries and territories contributed to the studies on gamification in education. While, predictably, the largest share of research (almost 13% of publications) comes from United States of America, Spain comes closely behind (almost 9%), followed by United Kingdom and Germany (both 5.4%) and then Brazil (4.2%), Portugal (3.3%), and Australia 3.1%. The last three countries that qualified to the top 10 are Italy (2.8%), Canada, and Malaysia (both 2.5%). The combined output of the top 10 countries constitutes 50.9% of the whole analyzed data set.

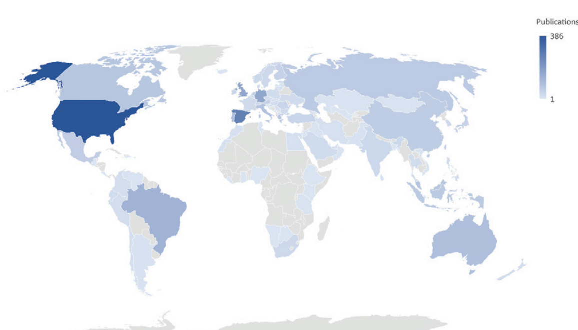


Figure 2. Number of publications coming from respective countries.

3.2.2. Forms of Publication

Figure 3 provides a visual answer to RQ3, showing the number of publications classified according to their types. As can be seen, over 63% of the analyzed items were conference papers, and a little less than 1/3rd were journal articles. Book chapters constitute less than 1/20th of the publications and books, about 1/180th of the whole set.

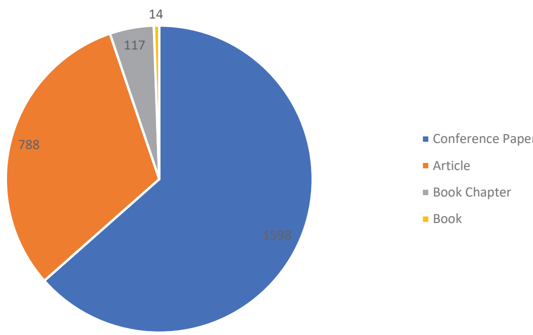


Figure 3. Number of publications of respective type.

3.2.3. Addressed Research Areas and Topics

With regard to RQ4, Figure 4 shows the number of publications attributed to respective research areas according to the classification used by Scopus (note that the Social Sciences category includes education sciences). Only the areas with at least 10 publications were included in the chart, but there were publications found corresponding to every area defined by Scopus. Note that many publications were classified as belonging to more than one category.

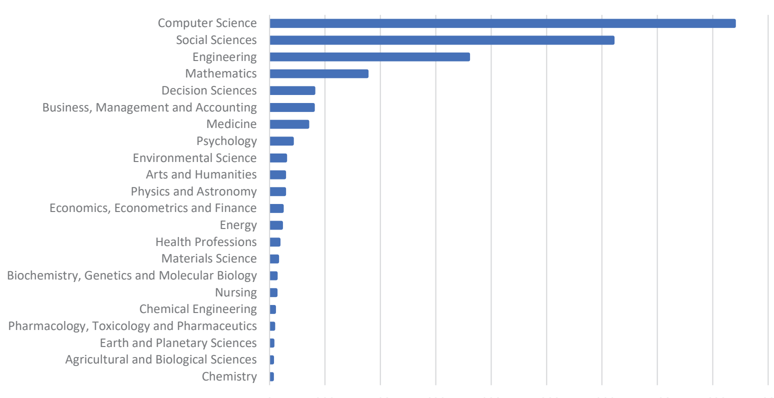


Figure 4. Number of publications from respective science branches.

Looking at Figure 4, Computer Science is the area presenting the most interest in gamification in education (about 1/3rd of the publications), followed by Social Sciences (about 1/4th), Engineering (about 1/7th), and Mathematics (about 1/14th). None of the remaining areas passed the threshold of 1/30th.

A more detailed information is provided in Figure 5, which addresses the question of specific topics covered by the research. It shows the map of co-occurrence of the most frequent keywords, generated using the VOS Viewer tool [46].

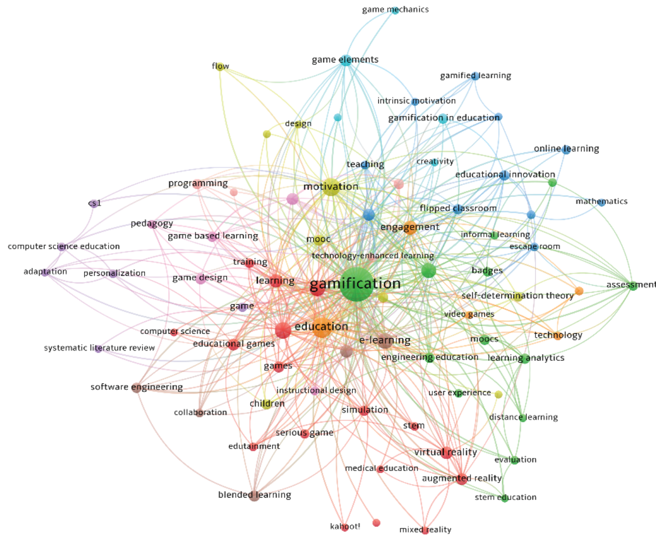


Figure 5. The most frequent keywords and their co-occurrence.

In Figure 5, the relative frequency of keywords is represented by their respective font size, the co-occurrence of keywords is represented with connecting lines, and the clusters of repeatedly co-occurring keywords are shown in the same color. Note that some keyword labels are missing for no other reason but the way VOS Viewer renders the graph.

Among the most frequent keywords, apart from gamification and education which were used in the query specification, four keywords passed the threshold of occurring in at least one percent of analyzed papers: motivation, serious games, game-based learning, and e-learning. Regarding the connections, apart from some easily predictable ones (e.g., learning—training, education—engagement, or gamified learning—intrinsic motivation) there are also some less obvious (e.g., virtual reality—medical education, blended learning—software engineering, or adaptation—computer science education).

3.2.4. Dissemination Channels

In response to RQ5, Figure 6 shows the seven publishing venues that were most often chosen by authors for dissemination of the research results on gamification in education. These include three conference proceedings series, three book series (also known to publish conference proceedings or post-proceedings) and only one journal. Together, these venues are responsible for 21% of the publications covered in the survey. The connected points depict the number of publications in each of these venues in respective years.

3.2.5. Most Involved Scientific Institutions

With regard to RQ6, altogether, there were 160 distinct institutions identified in the dataset retrieved from Scopus listed as an affiliation of at least one author. Table 3 lists the 20 most frequently encountered ones. Seven of them are based in Spain, which is quite a surprise even considering Figure 2. Similarly surprising is the fact than only one institution based in USA made it to the top-20 list.

3.2.6. Research Leaders

Addressing RQ7, Table 4 lists the authors of at least eight works covered in the query (their works combined constitute less than 1/3rd of the total analyzed output). There were 159 authors identified who authored at least three publications (this pertains to less than

3% of all contributors). While the most prolific authors are from Brazil, Portugal is the most represented country in the list with six authors.

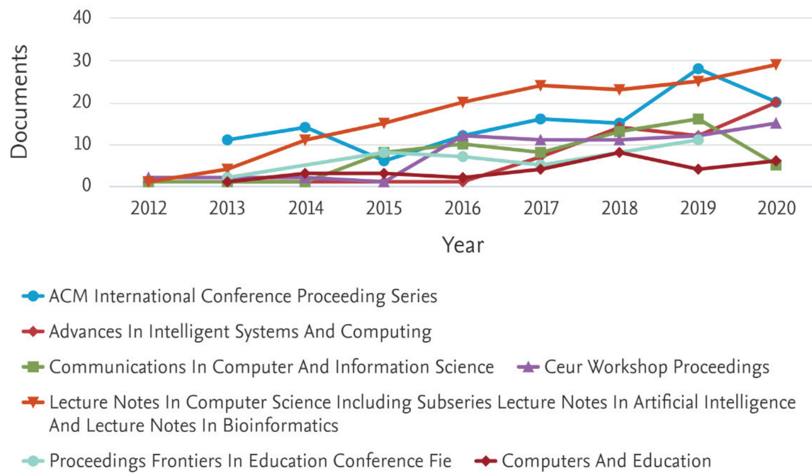


Figure 6. The most frequent publication venues.

Table 3. The most frequent affiliations of publication authors.

Institution	Country	Share
Tecnologico de Monterrey	Mexico	1.4%
Universidade de Sao Paulo—USP	Brazil	1.0%
Universidad de Salamanca	Spain	0.9%
Universidade Federal de Alagoas	Brazil	0.8%
The University of Hong Kong	Hong Kong	0.8%
Technische Universitat Graz	Austria	0.8%
Universitat Ramon Llull	Spain	0.8%
Universidade de Lisboa	Portugal	0.8%
University of Toronto	Canada	0.7%
Universidad Politécnica de Madrid	Spain	0.7%
Universidad de la Laguna	Spain	0.6%
Universitat Politècnica de Catalunya	Spain	0.6%
Universidad Rey Juan Carlos	Spain	0.6%
Pennsylvania State University	USA	0.6%
Open University of the Netherlands	The Netherlands	0.6%
IESCID Lisboa	Portugal	0.6%
Universidad de Granada	Spain	0.5%
Panepistimion Patron	Greece	0.5%
Curtin University	Australia	0.5%
Kazan Federal University	Russia	0.5%

3.2.7. Research Collaboration

Addressing RQ8, Figure 7 shows the map of the most prolific co-authors, generated using the VOS Viewer tool [46]. The number of publications is represented by the circle and font size of their respective author name, the co-authoring of publications is represented with connecting lines, and the largest clusters of authors working together are shown in the same color. Note that some author name labels are missing for no other reason but the way VOS Viewer renders the graph.

Table 4. The most prolific authors.

Author	Country	Works
Isotani, S.	Brazil	21
Bittencourt, I.I.	Brazil	16
Fonseca, D.	Spain	15
Toda, A.M.	Brazil	13
Berkling, K.	Germany	11
Hew, K.F.	Hong Kong	11
Villagrasa, S.	Spain	11
Antonaci, A.	The Netherlands	10
Barata, G.	Portugal	9
Dicheva, D.	USA	9
Gama, S.	Portugal	9
Gasparini, I.	Brazil	9
Paiva, J.C.	Portugal	9
Su, C.H.	Taiwan	9
Dichev, C.	USA	8
Hamari, J.	Finland	8
Huang, B.	Hong Kong	8
Jorge, J.	Portugal	8
Klock, A.C.T.	Finland	8
Leal, J.P.	Portugal	8
Meinel, C.	Germany	8
Queirós, R.	Portugal	8
Redondo, E.	Spain	8
Sillaots, M.	Estonia	8

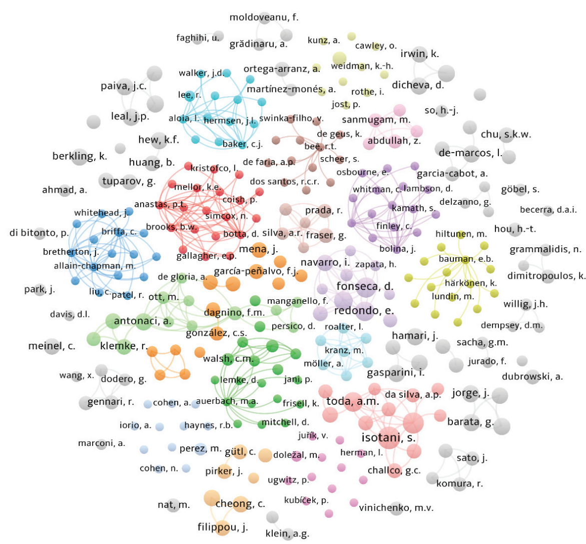


Figure 7. The map of co-authors.

Several large clusters are easily distinguishable; only few of them are built around the most prolific authors, including (as shown on Figure 7): Isotani and Toda (pale red), Fonseca and Redondo (heather) and Antonaci (pale green); more such clusters include only authors who contributed a small number of publications, such as: Anastas and Brooks (red), Walsh and Jani (green), Whitehead and Briffa (blue), Osbourne and Whitman (iris), Hiltunen and Bauman (olive) or Walker and Lee (cerulean).

3.2.8. Research Impact

With regard to RQ9, Table 5 lists the top 15 most cited works in the analyzed dataset. These works combined represent about 21% of the total number of citations (18,044, giving an average of 7.17 citations per indexed document). In total, 22 works (0.9%) passed the threshold of 100 citations, 379 works (15.1%) passed the threshold of 10 citations, and 1617 works (64.2%) were cited at least once.

Table 5. The most cited works on gamification in education.

Title	Authors	Year	Venue	Cited
Gamifying learning experiences: Practical implications and outcomes	Domínguez A., Saenz-De-Navarrete J., De-Marcos L., Fernández-Sanz L., Pagés C., Martínez-Herráiz J.-J.	2013	Computers and Education	712
Assessing the effects of gamification in the classroom	Hanus M.D., Fox J.	2015	Computers and Education	528
Defining gamification—A service marketing perspective	Huotari K., Hamari J.	2012	MindTrek Conference	523
Gamification in education: A systematic mapping study	Dicheva D., Dichev C., Agre G., Angelova G.	2015	Educational Technology and Society	519
An empirical study comparing gamification and social networking on e-learning	De-Marcos L., Domínguez A., Saenz-De-Navarrete J., Pagés C.	2014	Computers and Education	249
The effect of virtual achievements on student engagement	Denny P.	2013	Conference on Human Factors in Computing Systems	229
Foundations of Game-Based Learning	Plass J.L., Homer B.D., Kinzer C.K.	2015	Educational Psychologist	197
A recipe for meaningful gamification	Nicholson S.	2015	Gamification in Education and Business	187
A mobile gamification learning system for improving the learning motivation and achievements	Su C.-H., Cheng C.-H.	2015	Journal of Computer Assisted Learning	186
A systematic mapping on gamification applied to education	De Sousa Borges S., Durelli V.H.S., Reis H.M., Isotani S.	2014	ACM Symposium on Applied Computing	172
Gamification and serious games for personalized health	McCallum S.	2012	Studies in Health Technology and Informatics	158
Digital badges in education	Gibson D., Ostashewski N., Flintoff K., Grant S., Knight E.	2015	Education and Information Technologies	150

Figure 8 shows the map of co-citations for the 99 most prolific authors, generated using the VOS Viewer tool [46]. The number of 99 was fine-tuned to remove numerous outliers, with one large, one medium-sized, and just one small cluster remaining. The number of citations of an author is represented by the circle size, the co-citation of authors (a publication in which they are cited together) is represented with connecting lines, and the largest clusters of authors cited together are shown in the same color.

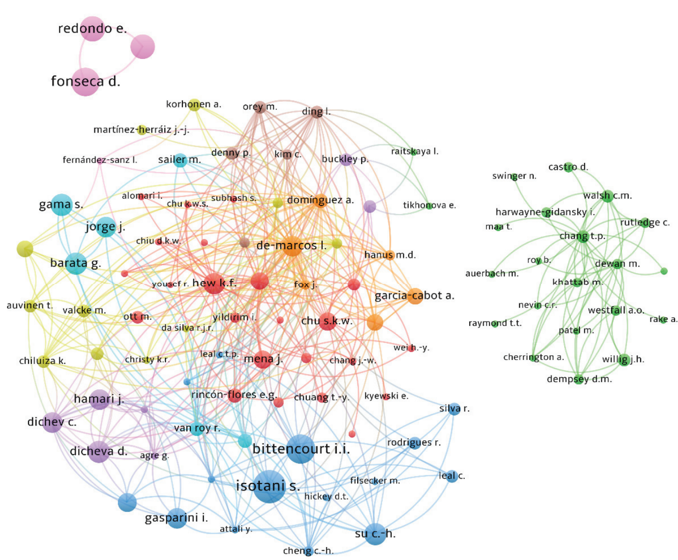


Figure 8. The map of co-citations.

4. Discussion and Conclusions

By applying the bibliometric approach based on data retrieved from the Scopus database (and to a lesser extent, Web of Science and Google Scholar), and using simple visualization tools we were able to respond to all nine of the stated research questions.

Regarding RQ1, the presented results show that, since 2013, gamification in education is a vivid and quickly developing area of research, with hundreds of new relevant publications coming out every year. As the data for the last year (2020) are not reliable (many publications are still in the process of indexation in the databases), it cannot be said that interest in the topic has already passed its peak: the data from the preceding years argue for the contrary. This observation is supported with the prior literature surveys in the area mentioning an increasing number of publications (see Table 1 and the works listed therein).

As for RQ2, the presented results indicate that even though there are countries (USA, Spain, United Kingdom, and Germany) leading the research, it is not dominated neither by a single country or a group of them, and the interest in gamification in education is widespread as about half of countries and territories of the world contributed to the research in the area. These findings are consistent with the recent observations by Grosseck et al. [18].

With respect to RQ3, research results regarding gamification in education are mostly disseminated at conferences, and journals are the second choice of the authors. Book chapters and books other than conference proceedings are relatively scarce. Note that the domination of conference proceedings is much more notable compared to surveys covering a smaller number of publications, e.g. [19].

Considering RQ4, the notion of gamification in education has already spread to all the research areas defined by Scopus. The area most often dealing with it is Computer Science. This interest may be attributed to various reasons, such as:

- Computer Science is a somewhat difficult subject of education, therefore the support for engagement and motivation offered by gamification is especially demanded (note also the high interest from the fields of Engineering and Mathematics);
- Computer Science subjects are mostly taught using computers, making it easy to introduce gamification software in the process compared to subjects traditionally taught without the use of computers;
- a considerable part of publications on gamification in education is devoted to presentation of new software tools, which, regardless of the area of education they are applied to, are often published in Computer-Science-related venues.

Regarding RQ5, consistently with the fact that the most preferred dissemination channel for the results of gamification in education research are conferences, the proceedings series are the dominating publishing venues for the area. The only journal that managed to attract a number of publications large enough to be listed among the conference proceeding series is "Computers and Education". This should serve as an indication for researchers coming to the area where to publish their results to reach the relevant audience.

With respect to RQ6, the interest in gamification in education is not limited to a handful of institutions, and those leading the field did not dominate it. As an illustration to the observed lack of dominance, the most frequent affiliation was one that none of the most prolific authors was affiliated with, and located in a country from outside the top 10 list (compare Tables 3 and 4 and Section 3.2.1).

Regarding RQ7, there is no huge gap in the number of publications between the leaders (the first spot is taken by S. Isotani who contributed with 21 publications) and the other authors, especially compared to other areas of research (consider e.g., the signal-processing guru, Harold Vincent Poor's 1809 publications indexed in Scopus). This may stem from the fact that gamification in education is relatively new field of research. The fact that only less than 3% of authors contributed with at least three publications indicates that research on gamification in education is usually a short-time activity rather than an area of scientific specialization.

In the context of RQ8, the presented results show that a number of collaborating researcher groups of various size have been established, however inter-group collaboration has been scarce so far. This may be interpreted in the context of the results of RQ7: in a short-time research there is little reason to reach out for collaboration outside of an established working group.

As for RQ9, both the high number of citations of the key works in the area and a large co-citation cluster involving multiple authors indicate that the research community acknowledges one another's work on gamification in education.

The results of RQ9 also support the correctness of the choice of search phrases: all the identified most-cited authors are actually contributors to the area of gamification in education. For a comparison, the list of top-cited authors in [18] lists such names as Deterding, Zichermann, Werbach, or even Deci, all of whom have important contributions to gamification research yet outside of the covered educational area.

In conclusion, we would like to underline the key observations from the performed survey: The fast growth of the publications in the area of gamification in education continuing for at least seven years. The worldwide interest in the area is indicated by the number of countries in which the contributing authors are based and the number of institutions to which they are affiliated. An effective research communication in the area is documented by the high number of citations and the large cluster of co-citations. We believe these findings can inspire new research in this field, both by confirming the ongoing interest in the area, and by revealing data such as the unexpected keyword connections, which allows new research questions to be pursued.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data were obtained from Web of Science, Scopus, and Google Scholar and are available from the author with the permission of their respective providers.

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

References

1. Kapp, K.M. *The Gamification of Learning and Instruction: Game-Based Methods and Strategies for Training and Education*; Pfeiffer: San Francisco, CA, USA, 2012.
2. Lamrani, R.; Abdelwahed, E.H.; Chraibi, S.; Qassimi, S.; Hafidi, M. *Gamification and Serious Games Based Learning for Early Childhood in Rural Areas. New Trends in Model and Data Engineering*; Abdelwahed, E.H., Bellatreche, L., Benslimane, D., Golfarelli, M., Jean, S., Mery, D., Nakamatsu, K., Ordonez, C., Eds.; Springer: Cham, Switzerland, 2018; pp. 79–90.
3. Alshammari, M.T. Evaluation of Gamification in E-Learning Systems for Elementary School Students. *TEM J.* **2020**, *9*, 806–813. [CrossRef]
4. Buzko, V.; Bonk, A.; Tron, V. Implementation of Gamification and Elements of Augmented Reality during the Binary Lessons in a Secondary School. *Pedahohika Vyshchoï Serednoï Shkoly* **2018**, *51*, 74–83. [CrossRef]
5. Varannai, I.; Sasvari, P.; Urbanovics, A. The Use of Gamification in Higher Education: An Empirical Study. *Int. J. Adv. Comput. Sci. Appl.* **2017**, *8*. [CrossRef]
6. Abdulmenaf, G.; Cigdem, U.B. Gamification in Adult Learning. In *Handbook of Research on Adult Learning in Higher Education*; Mabel, C.P.O., Tinukwa, O., Boulder, C., Eds.; IGI Global: Hershey, PA, USA, 2020; pp. 570–597. [CrossRef]
7. Denny, P.; McDonald, F.; Empson, R.; Kelly, P.; Petersen, A. Empirical Support for a Causal Relationship Between Gamification and Learning Outcomes. In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems—CHI'18, Montreal, QC, Canada, 21–26 April 2018; ACM Press: Montreal, QC, Canada, 2018; pp. 1–13. [CrossRef]
8. Sánchez-Sepúlveda, M.; Fonseca, D.; Calvo, X.; Navarro, I.; Franquesa, J.; Redondo, E.; Gené, M. Innovation in Urban Design Education. In Proceedings of the Sixth International Conference on Technological Ecosystems for Enhancing Multiculturality—TEEM'18, Salamanca, Spain, 24–26 October 2018; ACM Press: Salamanca, Spain, 2018; pp. 729–736. [CrossRef]
9. Kasahara, R.; Sakamoto, K.; Washizaki, H.; Fukazawa, Y. Applying Gamification to Motivate Students to Write High-Quality Code in Programming Assignments. In Proceedings of the 2019 ACM Conference on Innovation and Technology in Computer Science Education—ITiCSE '19, Aberdeen, Scotland, 15–17 July 2019; Association for Computing Machinery: New York, NY, USA, 2019; pp. 92–98.

10. Broman, K.; Maarell-Olsson, E. *Application of Digital Tools in Chemistry Education: Virtual Reality, Augmented Reality and Gamification. 2019 ESERA*; Umeå University, Interactive Media and Learning (IML): Umeå, Sweden, 2019.
11. Goehle, G. Gamification and Web-based Homework. *PRIMUS* **2013**, *23*, 234–246. [CrossRef]
12. Chapman, J.R.; Rich, P.J. Does educational gamification improve students' motivation? If so, which game elements work best? *J. Educ. Bus.* **2018**, *93*, 315–322. [CrossRef]
13. Dermeval, D.; Albuquerque, J.; Bittencourt, I.I.; Isotani, S.; Silva, A.P.; Vassileva, J. GaTO: An Ontological Model to Apply Gamification in Intelligent Tutoring Systems. *Front. Artif. Intell.* **2019**, *2*, 13. [CrossRef]
14. Swacha, J.; Queirós, R.; Paiva, J.C.; Leal, J.P.; Kosta, S.; Montella, R. A Roadmap to Gamify Programming Education. In Proceedings of the First International Computer Programming Education Conference (ICPEC 2020), Porto, Portugal, 23–24 April 2020; Schloss Dagstuhl-Leibniz-Zentrum für Informatik: Wadern, Germany, 2020.
15. Tenório, K.; Chalco Challco, G.; Dermeval, D.; Lemos, B.; Nascimento, P.; Santos, R.; Pedro da Silva, A. Helping Teachers Assist Their Students in Gamified Adaptive Educational Systems: Towards a Gamification Analytics Tool. In *Artificial Intelligence in Education*; Bittencourt, I.I., Cukurova, M., Muldner, K., Luckin, R., Millán, E., Eds.; Springer: Cham, Switzerland, 2020; pp. 312–317.
16. Hanus, M.D.; Fox, J. Assessing the effects of gamification in the classroom: A longitudinal study on intrinsic motivation, social comparison, satisfaction, effort, and academic performance. *Comput. Educ.* **2015**, *80*, 152–161. [CrossRef]
17. De Sousa Borges, S.; Durelli, V.H.S.; Reis, H.M.; Isotani, S. A systematic mapping on gamification applied to education. In Proceedings of the 29th Annual ACM Symposium on Applied Computing, Gyeongju, Korea, 24–28 March 2014; ACM: Gyeongju, Korea, 2014; pp. 216–222. [CrossRef]
18. Grosseck, G.; Malita, L.; Sacha, G.M. Gamification in Higher Education: A Bibliometric Approach. In Proceedings of the 16th International Scientific Conference—eLearning and Software for Education, Bucharest, Romania, 30 April–1 May 2020; eLSE: Bucharest, Romania, 2020; pp. 20–30.
19. Kocakoyun, S.; Ozdamli, F. A Review of Research on Gamification Approach in Education. In *Socialization—A Multidimensional Perspective*; Morese, R., Palermo, S., Nervo, J., Eds.; IntechOpen: London, UK, 2018. [CrossRef]
20. Silva, R.J.R.; Rodrigues, R.G.; Leal, C.T.P. Gamification in Management Education: A Systematic Literature Review. *BAR Braz. Adm. Rev.* **2019**, *16*, e180103. [CrossRef]
21. Martí-Parreño, J.; Méndez-Ibáñez, E.; Alonso-Arroyo, A. The use of gamification in education: A bibliometric and text mining analysis: Gamification in education. *J. Comput. Assist. Learn.* **2016**, *32*, 663–676. [CrossRef]
22. Majuri, J.; Koivisto, J.; Hamari, J. Gamification of Education and Learning: A Review of Empirical Literature. In Proceedings of the 2nd International GamiFIN conference, Pori, Finland, 21–23 May 2018; pp. 11–19.
23. Caponetto, I.; Earp, J.; Ott, M. Gamification and Education: A Literature. In Proceedings of the ECGBL 2014: Eighth European Conference on Games Based Learning, Berlin, Germany, 9–10 October 2014; pp. 50–57.
24. De Fabricio, C. Using gamification in education: A systematic literature review. In Proceedings of the International Conference on Information Systems 2018—ICIS 2018, San Francisco, CA, USA, 13–16 December 2018.
25. Legaki, N.; Hamari, J. Gamification in statistics education: A literature review. *CEUR Workshop Proc.* **2020**, *2637*, 41–51.
26. Milosz, M.; Milosz, E. Gamification in Engineering Education—A Preliminary Literature Review. In Proceedings of the 2020 IEEE Global Engineering Education Conference (EDUCON), Porto, Portugal, 28–30 April 2020; pp. 1975–1979. [CrossRef]
27. Klock, A.; Gasparini, I.; Pimenta, M.; Hamari, J. Tailored gamification: A review of literature. *Int. J. Hum. Comput. Stud.* **2020**, *144*, 102495. [CrossRef]
28. Dicheva, D.; Dichev, C. Gamification in Education: Where Are We in 2015? In Proceedings of the E-Learn: World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education 2015, Kona, HI, USA, 19 October 2015; Association for the Advancement of Computing in Education (AACE): Kona, HI, USA, 2015; pp. 1445–1454.
29. Subhash, S.; Cudney, E.A. Gamified learning in higher education: A systematic review of the literature. *Comput. Hum. Behav.* **2018**, *87*, 192–206. [CrossRef]
30. Osatuyi, B.; Osatuyi, T.; de la Rosa, R. Systematic Review of Gamification Research in Is Education: A Multi-method Approach. *Commun. Assoc. Inf. Syst.* **2018**, *42*, 95–124. [CrossRef]
31. Indriasari, T.; Luxton-Reilly, A.; Denny, P. Gamification of student peer review in education: A systematic literature review. *Educ. Inf. Technol.* **2020**, *25*, 5205–5234. [CrossRef]
32. Dicheva, D.; Dichev, C.; Agre, G.; Angelova, G. Gamification in education: A systematic mapping study. *Educ. Technol. Soc.* **2015**, *18*, 75–88.
33. Ortega-Arranz, A.; Muñoz-Cristóbal, J.A.; Martínez-Monés, A.; Bote-Lorenzo, M.L.; Asensio-Pérez, J.I. How Gamification Is Being Implemented in MOOCs? A Systematic Literature Review. In *Data Driven Approaches in Digital Education*; Lavoué, E., Drachsler, H., Verbert, K., Broisin, J., Pérez-Sanagustín, M., Eds.; Springer: Cham, Switzerland, 2017; pp. 441–447.
34. Ortiz Rojas, M.E.; Chiluiza, K.; Valcke, M. Gamification in higher education and STEM: A systematic review of literature. In Proceedings of the Edulearn16: 8th International Conference on Education and New Learning Technologies, Barcelona, Spain, 4–6 July 2016; IATED: Barcelona, Spain, 2016; pp. 6548–6558.
35. Hamari, J.; Koivisto, J.; Sarsa, H. Does Gamification Work?—A Literature Review of Empirical Studies on Gamification. In Proceedings of the 47th Annual Hawaii International Conference on System Sciences, Waikoloa, HI, USA, 6–9 January 2014; pp. 3025–3034. [CrossRef]

36. Alhammad, M.M.; Moreno, A.M. Gamification in software engineering education: A systematic mapping. *J. Syst. Softw.* **2018**, *141*, 131–150. [CrossRef]
37. Hallifax, S.; Serna, A.; Marty, J.C.; Lavoué, E. Adaptive Gamification in Education: A Literature Review of Current Trends and Developments. In *Transforming Learning with Meaningful Technologies*; Scheffel, M., Broisin, J., Pammer-Schindler, V., Ioan-nou, A., Schneider, J., Eds.; Springer: Cham, Switzerland, 2019; pp. 294–307.
38. Gari, M.; Radermacher, A. Gamification in Computer Science Education: A Systematic Literature Review. In Proceedings of the 2018 ASEE Annual Conference and Exposition, Salt Lake City, UT, USA, 23–27 June 2018; Volume 2018.
39. Nicholas, D.; Ritchie, M. *Literature and Bibliometrics*; OCLC: 3380191; Bingley: London, UK, 1978.
40. Schaller, A.A.; Vatananan-Thesenvitz, R.; Pulsiri, N.; Schaller, A.M. The Rise of Digital Business Models: An Analysis of the Knowledge Base. In Proceedings of the 2019 Portland International Conference on Management of Engineering and Technology (PICMET), Portland, OR, USA, 25–29 August 2019; IEEE: Piscataway, NJ, USA, 2019; pp. 1–13.
41. Baker, N.C.; Ekins, S.; Williams, A.J.; Tropsha, A. A bibliometric review of drug repurposing. *Drug Discov. Today* **2018**, *23*, 661–672. [CrossRef] [PubMed]
42. Yoopetch, C.; Nimsai, S. Science Mapping the Knowledge Base on Sustainable Tourism Development, 1990–2018. *Sustainability* **2019**, *11*, 3631. [CrossRef]
43. Hallinger, P.; Chatpinyakoop, C. A Bibliometric Review of Research on Higher Education for Sustainable Development, 1998–2018. *Sustainability* **2019**, *11*, 2401. [CrossRef]
44. Giustini, D.; Boulos, M.N.K. Google Scholar is not enough to be used alone for systematic reviews. *Online J. Public Health Inform.* **2013**, *5*, 214. [CrossRef]
45. Aksnes, D.W.; Sivertsen, G. A Criteria-based Assessment of the Coverage of Scopus and Web of Science. *J. Data Inf. Sci.* **2019**, *4*, 1–21. [CrossRef]
46. Van Eck, N.J.; Waltman, L. Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics* **2010**, *84*, 523–538. [CrossRef] [PubMed]

education sciences

MDPI

Article

Formative Potential of the Development and Assessment of an Educational Escape Room Designed to Integrate Music-Mathematical Knowledge

José Carlos Piñero Charlo [1,*], Paula Ortega García [1] and Sara Román García [2]

[1] Departamento de Didáctica, área de Matemáticas, Facultad de Ciencias de la Educación, Universidad de Cádiz, 11510 Puerto Real, Spain; paula.ortegagarcia@alum.uca.es

[2] Departamento de Didáctica de la Educación Física, Plástica y Musical, Facultad de Ciencias de la Educación, Universidad de Cádiz, 11510 Puerto Real, Spain; sara.roman@uca.es

* Correspondence: josecarlos.pinero@gm.uca.es; Tel.: +34-660-584895

Abstract: In the particular case of Spain, student and teacher difficulties associated with the mathematical discipline have been evidenced in PISA and TEDS-M reports. As we consider that the teachers' difficulties are connected to the students' performance, we propose a multi-disciplinary approach to deliver specific didactic/mathematical knowledge to the trainee teachers. Such additional instruction shall be meaningfully connected to the real needs of the schools, so a service-learning approach is proposed here. In the present manuscript, the trainee teachers have co-designed educational escape rooms (in coordination with local schools) with the aim of mobilizing curricular knowledge. The goal of the educational escape rooms is to foster the mathematic-related competencies by establishing meaningful connections to other curricular disciplines (music-related knowledge, in the case of this study). This paper reports on the particular experience developed with a group of students (trainee teachers) while designing their educational escape rooms, focusing on the particular case of a specific student to evidence the formative potential of the procedure. The didactic suitability of the proposed escape room has been analyzed and professional development has also been discussed, showing the mobilization of relevant professional skills and fostering the related music and mathematical didactic competencies by shifting the teaching perspective from an algorithmic point of view to a more "reasoning and designing" strategy. This constitutes an evidence of the formative potential on the co-design of educational escape rooms, when designed in the frame of a service learning approach.

Keywords: teacher instruction; motivation; curricular integration; mathematics instruction

Citation: Piñero Charlo, J.C.; Ortega García, P.; Román García, S. Formative Potential of the Development and Assessment of an Educational Escape Room Designed to Integrate Music-Mathematical Knowledge. *Educ. Sci.* **2021**, *11*, 131. https://doi.org/10.3390/educsci11030131

Academic Editor: David Geelan

Received: 15 February 2021
Accepted: 15 March 2021
Published: 18 March 2021

1. Introduction

A school's curriculum may appear unrelated, fragmented or somewhat disjointed due to the lack of communication and connection among topics and subjects. This fragmentation often affects students' performance inducing lack of interest and confusion, thus, perceiving some knowledge as useless and affecting the experience being delivered to them in school [1]. Indeed, some core curricular subjects seem to be clearly affected by these problems, particularly scientific and mathematical knowledge. For the particular case of Spain, schoolchildren show their worst results in scientific knowledge in PISA [2] tests (scoring below the OECD average). The PISA 2018 report indicates that such a result might be due to students' lack of capacity to formulate, manage, and interpret mathematics in a variety of contexts. This bad performance might be related to the lack of connections of scientific/mathematical knowledge to other curricular topics, but might also be related to their teachers' specific lack of knowledge. Indeed, for the sake of comparison, PISA statistic data can be compared to that of the TEDS-M report [3], thus, giving information on the teachers' specific lack of mathematical knowledge. In doing so, worrisome data regarding the mathematical and didactic knowledge of on-service teachers are revealed (see Figure 1). These results reveal the key importance of specific "mathematical training programs" for teachers' education, with Spain teachers lightly below the mean score for both didactic and mathematic knowledge. In this regard, Figure 1 shows the average performance of 15-year-old students in mathematics (regardless of the school type and grade attended), evidencing a wide gap between the Spanish score (blue line) and the average OECD score (orange line). Figure 1 also shows the score provided by the TEDS-M report for the didactic-mathematical knowledge of on-service teachers, where Spanish teachers are also below the OECD average.

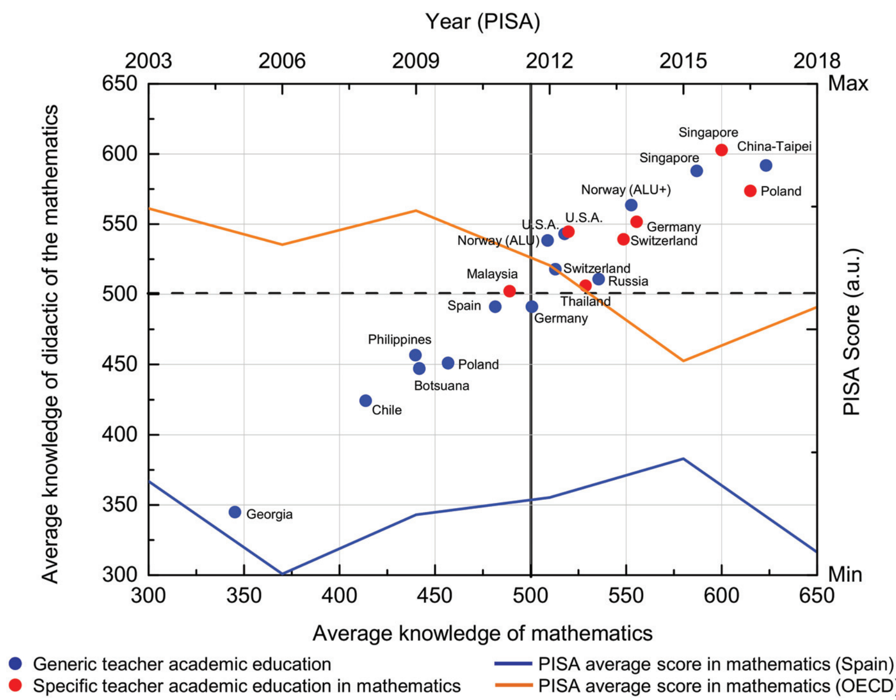


Figure 1. Teachers' didactic-mathematical knowledge by country (blue and red dots) and average performance of Spanish students in PISA -Programme for International Student Assessment- tests (thick red line). Adapted and translated from: Ministerio de Educación, Cultura y Deporte TEDS-M -Teacher Education and Development Study in Mathematics- database. Retrieved from: TEDS-M report 2012 and PISA reports.

Attending to Figure 1 data, it is clear that countries with a specific teacher education in mathematics score higher that those with a generic teacher education. Furthermore, the poor performance of Spanish students could be related to the low didactic-mathematical knowledge of their own teachers.

Therefore, two main challenges should be attended: (i) To solve the "curricular isolation" of the mathematics discipline, promoting the ability to establish connections and (ii) designing a specific teacher academic education in mathematics as a way to improve didactic-mathematical knowledge.

This manuscript constitutes a research report, showing data corresponding to a "mentoring program" to deliver specific didactic-mathematic education to students (trainee teachers). We would like to face both challenges at once, creating a framework to treat the "isolation" and the low didactic knowledge in mathematics. To solve the perceived "curricular isolation" of the mathematics discipline, the use of curricular integration techniques can be an approach, which may help establish connections. In this regard, Anglin [4] insights that "integrating curriculum correctly requires more than combining two subjects, or turn teaching". Therefore, in effective curriculum-integration models knowledge is meaningfully related, connecting in such a way that it becomes relevant to other areas of learning, as well as in real life.

In this contribution, the authors assume that a curricular integration approach may lead to a significant improvement in the students' mathematical skills (including reasoning mathematically and using mathematical concepts, procedures, facts, and tools to describe, explain, and predict phenomena). It is also assumed that curricular integration may motivate students to perceive mathematical knowledge as useful. Finally, a schoolchild and future teachers should "enjoy while doing mathematics", so a gamification approach is also considered. The main goals of this study can be summarized as:

- Explore the efficiency of a specific program designed to develop students' mathematical competencies in the frame of an integrated curriculum, with the aim of:
    - Delivering specific didactic-mathematical knowledge in touch with on-service teachers and schools.
    - Designing, analyzing, and implementing problem-solving scenarios (educational escape rooms) as a way to mobilize professional didactic-mathematical skills.
- Manage students' "math-phobia": The trend of students and the schoolchild that fear the mathematical discipline. Math-phobia has to be treated since no knowledge can be built over a bad relation with the discipline. Thus, a gamification approach is used to boost students' capacities to employ mathematical concepts in a variety of contexts. Curricular integration is used here as a tool to motivate students to develop didactic skills and mathematic knowledge taking the music discipline as a source.

To do so, the authors (researchers and teachers at the University) have created a mentoring program formalized as two academic year's student/teacher cooperation. The goal of the mentoring program was to improve the didactic-mathematical knowledge of participant students (trainee teachers). This goal should be achieved in two stages (each one, corresponding to a different academic year). Both years would be dedicated to solve specific mathematical difficulties reported by on-service teachers in cooperating schools. Difficulties would be treated by designing gamified environments (educational escape rooms), specifically developed to mobilize mathematical competencies in a curricular integration approach. That is, students should design an educational escape room which shall mobilize curricular knowledge as a way to promote connections and relations among the different curricular subjects. In doing so, some research questions should be answered by the students: Can an educational escape room be used to work music and mathematical knowledge? How can music and mathematics didactic situations be analyzed?

The project started with a small group of five cooperating students, creating a team able to design, implement, evaluate, and re-design such educational escape rooms in close relation to cooperating primary education schools (CEIPs). This procedure allows students (future teachers) to enjoy a "specific mathematic education", in close relation with their own interests, while providing valuable support to the CEIPs. Students should have accomplished the core mathematic education of the "Primary Education Degree" of the University career, so the 2-year cooperation was designed to go beyond the core instruction.

In this manuscript, we present one of the educational escape rooms designed by one of the five cooperating students, analyzing its didactic suitability, exploring the possibilities of curricular integration, and analyzing the professional development achieved by this specific student.

2. Background and Framework

As mentioned in the Introduction Section, this manuscript presents an educational escape room (EER) designed by students with the aim of mobilizing mathematic competencies, while emphasizing connections in a curricular integration approach. EER should be useful to treat specific mathematic difficulties reported by the on-service teachers. Therefore, as the aim of this procedure is the implantation and evaluation of the designed EER, students have been in touch with the cooperating schools (coordinating, scheduling, and programming the interventions). This section presents a brief discussion of the theoretical framework which inspired the core ideas of the study.

2.1. The Need for Curricular Integration

Criticism of a standards-based curriculum began when the National Council of Teachers of Mathematics (NCTM) [5] produced the Curriculum and Evaluation Standards for Schools in 1989 [6]. Since then, numerous evidences have been reported on the effects of changing from a traditional mathematics curriculum to an integrated mathematics curriculum on student mathematics learning [7,8]. In Europe, and as a consequence of the Bologna Process (a European process to adapt education to the new reality), an aptitude-based perspective has been used to inspire the new curricula [9,10]. In this context, adopting curricular integration approaches have been recommended in all educational stages.

Curricular integration is a way to promote interdisciplinary teaching, and can be defined as a method used to teach across curricular disciplines, with the aim of bringing together previously separated disciplines around common themes, issues or problems [11]. Literature [12] identifies seven common elements which are shared among different integrated curriculum approaches: (i) A combination of subjects, (ii) an emphasis on projects, (iii), the use of a wide variety of source material beyond textbooks, (iv) highlighting relationships among concepts, (v) thematic units, (vi) flexible schedules, and (vii) flexible student grouping. Curricular integration approaches have become more and more widespread as the emphasis of the learning process has emphasized on connections and skill development rather than on curricular disciplines [13].

One way curriculum developers have created a standards-based curriculum is by arranging consecutive integrated courses, which incorporate different content and process standards [14]. However, this can in fact lead to a disintegration of curriculum if great care is not taken to review and base learning on the previous year's topics [15]. Since an integrated curriculum generally alternates between content strands, students can lose the understanding of mathematical systems [15], so a problem-based approach is required.

In the particular case of Spain, curricular integration approaches are being used to give an answer to students who ask "what is this knowledge useful for?", since "meeting the reality is one of the aims of an educational system" [16]. In this regard, J. Torres [16] spotted that "some knowledge will only make sense when integrated with the living reality".

In the present contribution, authors aim to educate students (future teachers) for an effective music-mathematical integration. In this regard, the proposal aims to encourage our students to allow children in primary and early childhood education to explore and play in both music and mathematics and to experience the synergy of exploring the two subjects as one. For future teachers to be confident in their ability to incorporate integrated approaches in the teaching of music and mathematics, teachers may need to re-conceptualize what it is that makes an activity "musical" and "mathematical". This may require support from higher education tutors and teachers and is likely to take time to develop. However, experience to date indicates that, when experienced teachers and trainee teachers engage in appropriate activities for themselves, they quickly develop the confidence to explore the activities further and even go on to create activities of their own [17]. Finally, the proposed approach is supported by previous research [18], which reports that teachers became more comfortable at the global thought of integrating music and core academic objectives, with a slight increase in the confidence level in integrating music with reading, math, science or social studies objectives.

2.2. Co-Design of Didactic Situations

Some authors report that a real empowering in learning processes can be achieved by the educational co-design [19]. Participatory design (originally co-operative design, now often co-design) is an approach to design attempting to actively involve all the participants in the design process to help ensure that the result meets their needs and is usable. In the particular case of education, participatory design should allow students to investigate and develop their own learning processes via peer-to-peer discussions and teachers' feedback [20]. In this regard, the co-design of didactic situations shall fit with the principles mentioned in literature [21,22], which can be summarized in:

- The activities should allow students to manipulate and control tools useful to fit the problem.
- The tasks should enable the skill to customize and explore the problem autonomously.
- The complete experience should provide opportunities to visualize the problem from a different role (as a reviewer, solver, etc.)

In the case of this manuscript, the co-design approach is used to fit creative tasks cooperatively developed by on-service school teachers, students, and the authors of this manuscript (researcher and teachers at the University). Participatory design processes should be based on a question to be solved, whose treatment could be supported and enhanced by the use of virtual learning networks [23]. With the aim of respecting such principles, the procedure employed in this research involved the creation of a small "designer team" (constituted of five students). To enhance the process, this "designer team" should be coordinated in the creation of problems, activities, tasks, tests, narrative, etc. to be taken into account when designing an EER. On-line and face-to-face meetings with the researchers in charge (authors of the manuscript) were scheduled, in order to provide feedback to the students. Moreover, virtual meetings with on-service teachers at the school were also scheduled to verify that the designed EERs were fitting with their needs, as well as to plan different implementations.

2.3. A Service-Learning Approach

In 1979, Robert Sigmon [24] defined service-learning as an experiential education approach that is premised on "reciprocal learning" suggesting that since learning flows from service activities, both those who provide the service and receive it "learn" from the experience. In Sigmon's view, service-learning occurs only when both the providers and recipients of the service benefit from the activities. Since its original idea, service-learning has evolved to become a methodology, a teaching-learning tool (and even a pedagogy by itself) that combines the service to a community with the professional formation and the needed reflection, which enrich the learning experiences of students and teachers [25].

Nowadays, service-learning is considered an educational approach that combines learning objectives with community service in order to provide a pragmatic, progressive learning experience, while meeting societal needs. This methodology involves students in service projects to apply classroom learning for local agencies that exist to effect positive change in the community.

In this particular study, authors have assumed a service-learning approach to boost students' learning experience, while meeting the school needs (specifically, schoolchildren's mathematical difficulties). With this approach, researchers would like to simultaneously attend to the students and schoolchildren's mathematical difficulties. This approach aims to contribute to solve the situation spotted in the Introduction (see Figure 1). In the presented experience, university students (primary education trainee teachers) have cooperated with several schools to design and implement educational escape rooms that fit the specific school needs.

2.4. Educational Escape Rooms as a Formative Tool

A conventional escape room consists of a live-action, team-based game where players are jailed in a room where they will have to solve puzzles in order to unravel a story and escape before the available time ends. Using mathematical puzzles (such as situations of calculus resolution, data acquisition, probability determination, etc.) the players get access to a combination of numbers that enables them to open mechanisms that grant access to other puzzles. The last enigma (or the combined result of some enigmas), grants the final code to escape the room. Finally, there is a "game master" supervising the escape room experience, who can eventually communicate with the players.

In this contribution, the authors' starting hypothesis considers that an escape room-based activity might be a powerful educational resource to create learning opportunities for primary-school schoolchildren, but also to promote professional skills on trainee teachers by designing EERs. This approach is shared by other authors in literature [26]. Using an EER to tell a story, students are transformed into protagonists of an escapism tale and, to have success, they will have to mobilize curricular knowledge (conveniently fitted to the educational level of the students). In addition, this resource fosters collaboration, allowing the development of social skills (cooperation between players is essential to complete the adventure). Furthermore, the EER can be used to deliver an integrated experience, so that knowledge is not isolated but meaningfully connected to the different clues, tools, enigmas, scenery, and other elements of the ERR.

We have already demonstrated the potential of EERs to promote knowledge [27], by designing the experience of a problem-based game and emphasizing the equivalent game-problem [28,29]. In this regard, the literature reports that problem-based learning approaches may help mitigate the different mathematics performances evidenced in PISA reports [30]. Design criteria and guidelines were provided to students, but the proposal presented here could not be implemented (due to the COVID-19 pandemic). Therefore, the potential of the EER in terms of "useful teaching tool to be used in primary education" could not be presented in this manuscript. However, the students' design of EERs will be evaluated in terms of professional development, analyzing the didactic suitability as well as the fit to the design criteria, needs of the school, and success as a curricular integration tool.

3. Methodology

In January 2017, the project started with the idea of co-designing gamified environments (educational escape rooms—EERs) so that students have a way to interact with on-service teachers, researchers (authors of the manuscript), and schoolchildren. The goal of the project was to promote didactic and mathematic knowledge in a meaningful way for both students and schoolchildren.

3.1. Design-Based Research and Didactic Engineering

Design-based research (DBR) is a family of methodological approaches for the study of learning in context [31]. It uses the design and systematic analysis of instructional strategies and tools, trying to ensure that instructional design and research are interdependent. In a first practical approach, DBR consists of orienting research to introduce innovations in education. One of the DBR main characteristics is the introduction of new elements that shall transform the situation [32]. DBR aims to provide answers to real problems (detected in the educational reality) taking scientific theories or theoretical models as a starting point which is available for solving such problems. To this aim, programs, didactic packages, tools, didactic strategies, etc. are designed, tested, and validated so, once improved, can be diffused to the school reality.

The design-based research process is often presented in two stages: (i) The research process until a new product is created and the successive improvements, and (ii) delivering knowledge so that new principles can contribute to the new design process. The product is not only composed of material tools (textbooks, video, computer apps or simulations, etc.) but also composed of processes and procedures (teaching methods, schoolchildren scheduling plans, didactic strategies, etc.).

On the other hand, "didactic engineering" (DE) was introduced in the French Didactic of Mathematics in the early 80s to describe a research approach in mathematics education comparable to an engineer's work. Since its origin, didactic engineering was fundamentally connected to educational interventions (experiments) in classrooms, usually sequences of lessons. These experiences were guided by and tried to test some theoretical ideas. That is, DE is conceived as the design and evaluation of theoretically justified sequences of mathematical teaching, with the intention of triggering the emergence of some educational phenomena, and developing teaching resources scientifically tested. DE is based on the theory of didactical situations [31,32] and involves the experimentation (classroom teaching interventions) and validation via a priori and posteriori analysis. In this manuscript, a combination of DBR with DE (which have common terms, as stated in literature [33,34]) is used.

3.2. Participants and SAMPLING

By the year 2018, a group of five cooperating students voluntarily conform a mentored "designer team" (supervised by the authors of this manuscript). Such a team should act in coordination with different primary education schools (CEIPs) of the province. In the 2017/18 academic year, three different CEIPs were interested in the implementation of EERs. However, the demand highly increased in 2019 and the project was expanded to interact with conventional courses, so more students could cooperate on the initiative. This project is being developed at the University of Cadiz. Students belong to the "Primary education degree" and have a mean age of 21 years. Two lines are actually being developed:

1. Design and implementation of EERs: This line is being developed by a group of five cooperating students in close relation with on-service teachers at schools. They have already finished their conventional curricular education in the university degree, so this project acts as a specific and additional didactic-mathematic formation (with a strong emphasis on establishing connections by curricular integration methodologies). This line is in the core of the present manuscript.
2. Didactic analysis of EER experiences: This line uses the recorded data of the first line to share real didactic experiences with other trainee teachers (so more students could benefit). As EERs have been designed to mobilize mathematic skills and knowledge, the transcribed situations can be used to develop a variety of items of the conventional trainee teachers' curricula. This line is out of the focus of the manuscript, but some results have already been published [17] and is briefly presented here to provide a full view of the picture.

Figure 2 summarizes the procedure and methodologies used in line 1, emphasizing the use of the results provided by this line to ease real didactic situations that are used in conventional lectures with students. As presented in Figure 2, implementation of the designed EER occurs after a co-design phase, while service-learning stages are present at the beginning and the end of each cycle.

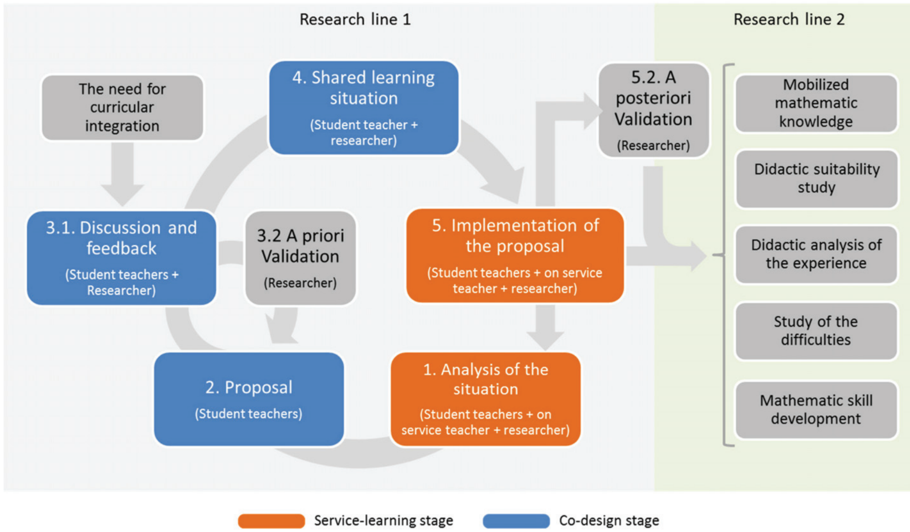


Figure 2. Schematic of the two research lines in the project. Line 1 focuses on the co-design of Educational Escape Rooms as a way to expand didactic-mathematic knowledge, as well as to establish connections via curricular integration methodologies. Implementation of the designed educational escape room (EER) occurs after a co-design phase, while service-learning stages are present at the beginning and the end of each cycle.

While the co-design of the EERs is carried out by a group of five cooperating students, the designed experiences are implemented in different schools of the province (to date, seven CEIPs have been cooperating with the project), so more than 200 schoolchildren have already participated in the project. The transcribed experiences are then used to carry the didactic analysis and to develop curricular elements/professional competencies of the students participating in line 2. Summarizing, to date:

- Line 1: Five cooperating students have been involved in designing, implementing, analyzing, and re-designing EERs (in touch with on-service teachers and local schools). The average age of these students was 23 years.
- Line 2: Results obtained in line 1 have been shared with other trainee teachers, showing the different didactic experiences in conventional lectures. Up to 142 students, with a mean age of 21 years, have participated in this line in the 2019–2020 and 2020–2021 academic years.
- As a consequence of the interaction with local schools, one meaningful byproduct of the project is that more than 200 schoolchildren have participated in EER experiences. The implemented EERs were designed and implemented in all primary education levels, so schoolchildren aged between 6 and 12 years have been participating in the different implementations.

The presented EER was co-designed by one of the five cooperating students, as a previous step of her final career work, let us label her as "cooperating student #4" (CS#4). She participated in designing EERs (as part of the first stage of the 2-year cooperation) prior to designing a whole EER by herself. The experience of this student takes the authors' attention due to her initial bad emotional relation with the mathematics discipline, while exhibiting high performance in other areas. Knowing her math-phobia, this student requested to be incorporated in the group of cooperating students as a way to go further in her didactic-mathematical knowledge. Researchers seized the opportunity to connect her fears (the mathematics) with her passions (the music).

CS#4 started developing EER tasks as part of the "designer team", following the conventional cycle proposed in Figure 2 for research line 1. She had the opportunity to implement a team-designed EER during the first year of cooperation (prior to the 2020 pandemic situation). CS#4 had completed her conventional didactic-mathematic formation available in the "primary education degree", so she was familiar with the design criteria, [27] as well as the didactic situations theory [35]. Her goal was to establish connections among the mathematic and musical knowledge in the frame of an EER, so that the narrative and tasks contained concepts, procedures, strategies, and skills from both disciplines. This report focused on CS#4 achievements due to the limited extension of the manuscript. However, achievements of the complete "designer team" are also briefly presented and discussed.

3.3. Design Guidelines

Some educational escape rooms design guidelines are available in literature [36,37], lacking, in some cases, scientific references supporting such guidelines. The literature has plenty of "false" escape rooms [38,39]: Players are accompanied by the teacher or the escape room experience is reduced to an "opening a box" in a conventional lecture. Indeed, in such kind of approaches, players do not have to escape from any room. Educational escape rooms are yet in an emergent situation, so there is still some misinformation and confusion.

3.3.1. EER Design Criteria

The previously described situation sets the point to establish specific criteria for defining "what an educational escape room is". In this regard, design criteria were established by the authors as presented in [27], so that students can apply such criteria when designing their proposals. Design criteria can be summarized as follows:

- Dynamism: Linked problems and enigmas should be designed to be solved in a brief time.
- Performance: The EER has to be fitted to the knowledge level of the student/players. Specific difficulties, detected during the conventional course, should be addressed during the game, creating a framework where peer-to-peer discussions help overcome such difficulties.
- Communication: Once the escape experience is finished, a final discussion is needed.
- Isolation: Players have to be isolated in a room, with an appropriate scenario recreating the narrative. Communication among players and the teacher is limited to a radio.
- Continuity: EER should be meaningfully connected to the concepts that are being worked on the conventional lectures. Moreover, scenery and storytelling might create an immersive experience [40] and be used to fit with an integrated curriculum approach.
- Curriculum: Enigmas and problems of an EER should mobilize the curricula (fitting with NTCM [41]) in the case of the mathematics curriculum.
- Assessment: Finally, as in any educational experience, an EER constitutes an activity where the development of certain competencies should be assessed.

Most of these criteria are coincident with traditional parameters used for designing and scheduling conventional educational situations [42].

3.3.2. EER Experience Analysis Model

As part of the formative process, students are committed to carrying a didactic analysis of the implemented experiences. Didactic analysis is a common term used in didactic of the mathematics' research and includes a set of concepts and methods widely used by research groups, highlighting conceptual and procedural aspects [43]. In this project, a validated model created by Font [44] has been used. However, such a model was designed to perform the mathematic education practice analysis, while the experience proposed by the student aims to be curricularly integrated. This implies that Font's model was to be "expanded" to cover the range of music-related practices. Such "expanded model" was co-designed by the student CS#4 in touch with the multi-disciplinary team of researchers in charge (authors of this manuscript). The resulting model is briefly presented as a result in the present contribution.

3.4. Evaluation: Tracking Students' Learning Process

Evaluation is an essential part of every learning-teaching process. When considering how to evaluate students, one has to realize that different evaluation tools should provide different information [45]. Therefore, researchers designed a sequence of tasks, deliverables, and evaluation tools to assess students' performance. For example, to track the students' learning process, face-to-face and online meetings were scheduled. Furthermore, deliverables were required as part of the students' practice interaction with schools:

- An on-line diary was to be delivered on-line and weekly reviewed by the researchers.
- Three to five practical interventions were to be designed, implemented, documented, and reported to the researchers in charge (this was an agreement with local schools).

In parallel, students were co-designing the EERs according to the documented schoolchildren's difficulties. The design of the EER was tracked by meetings and interviews with the researcher, so that the creative process was not interrupted but boosted by new ideas. That is, the evaluation is conceived here as a way to support students in their creative look for didactic-mathematical knowledge [46]. The different evaluation tools, tasks, and learning goals are summarized in Table 1.

Table 1. Deliverables and evaluation tools used in this research.

Task	Type	Educational Goal
On-line diary of the activity on the cooperating school	Diary deliverable, weekly review, and feedback	Identify, track, and discuss schoolchildren's mathematical difficulties
Design, implement, and analyze 3–5 interventions	Flexible deliverable, on-line review	Identify, track, and discuss students' own didactic difficulties
Report of the designer team	Monthly meeting, interview	Track the state of the co-designed EER
Questionnaire	Initial and final	Track students' attitude through the formative process
Final degree thesis	Final deliverable, evaluated by a committee	Provide evidences of promotion in the didactic-mathematical knowledge

4. Results and Discussion

While the co-design of the EERs is carried out by a group of five cooperating students, the designed experiences are implemented in different schools of the province (additional information on the characteristics of the sample is provided in Section 3.2). The proposed experience [47] was co-designed to be implemented in a specific school with a medium-low social-cultural and economic level. All activities were designed to fit the sixth academic course of the Spanish Primary Education curricula, as well as to fit the psychological characteristics of students aged between 11–12 years. The whole escape room experience was designed to be autonomously accomplished in 45 min. Mathematical tasks of the presented experience were designed to connect spatial orientation, spatial quantification, maps' interpretation, problem-solving skills, and mathematical reasoning. Mathematical tasks were designed to fully connect with music-related concepts such as active audition, timbral source recognition, and music style recognition. Finally, the proposal was designed to be solved by heterogeneous groups of 4–5 schoolchildren and to mobilize contents and skills from different academic fields: Mathematics (logic, arithmetic, geometry, and spatial orientation) and music (active listening, audio-visual timbre identification, and musical genres).

4.1. Result 1: Adapting the Original Didactic Analysis Model

As a service-learning approach, the "analysis of the situation" and difficulties reported by CEIPs set the starting point of the experience (see Figure 2). Since students have to reply to the CEIP-reported difficulties, the following research questions emerge: Can an educational escape room be used to work music and mathematic knowledge? How can music and mathematics didactic situations be analyzed? To provide the initial literature, students are initiated in Font's model [44], applying such a model to analyze pure mathematic didactic situations. Once the students became familiar with the original model, they were invited to propose slight modifications to be introduced in the model (so that it covers a music-mathematical analysis). In this section, we present the adaptation of the original Font's model co-designed by CS#4 and the authors.

4.1.1. Identification of Musical and Mathematical Practices

This level of analysis focuses on actions with different natures (discursive, operative, etc.) that schoolchild-players have to do in order to solve the situation-problem. As the problem in the EER belongs to different branches of knowledge, the analysis of the implemented experience should differentiate musical practices from mathematics. However, when involving students in situations of curricular integration problems, it may happen that the practices developed coincide in form, not in content.

4.1.2. Knowledge and Practice

In Font's model, it is clear that students have to mobilize mathematical concepts and skills which enable a proper interpretation of the obtained results. Therefore, the language used as well as the procedures and arguments (as a fundamental part of the mathematic reasoning) have to be analyzed.

Taking the literature as a reference [48,49], music-related declarative and procedural knowledge ("knowing that" vs. "knowing how") should be included in this level, due to its similarity with the original design of the model [50]. "Knowing music" involves both, the assimilation of contents (facts, propositions, theoretical systems, etc.) and the development of specific skills (such as audition, interpretation, and creation [48]). Musical declarative knowledge should be meaningfully connected to the proposed situation-problem. On the other hand, a proper analysis of the musical procedural knowledge should contemplate:

- Audition: In this stage, the focus of the analysis is the identification of sounds and recognizing its relation to the timbral source (depending on the musical style). The study of both dimensions is based on the theories and pedagogical principles presented in literature [51,52], which makes an emphasis on the soundscape and the acoustic ecology.
- Composition: In a music-mathematic environment, a situation-problem may require a compositional musical dimension, which should take into account the appropriate use of musical parameters in contrast to an intuitive performance of the compositional act [48].
- Interpretation: The solution of a problem-based situation may involve the interpretation of a musical piece or a melodic pattern on an instrument. In such a case, the technique used should be analyzed, taking into account the musical interpretation [48].

4.1.3. Interactions and Conflicts

The treatment of the interactions produced during the problem-solving process must be analyzed [44]. The different activities which compose the whole EER should motivate the communication among the participants. Such communication might involve different parameters, such as cognitive, epistemic, interactional, etc.

4.1.4. Norms

This level of analysis involves the creation of norms and generalities derived from the musical and mathematical practice.

4.2. Discussion 1: Towards a Curricular Integration Analysis Model

Based on the co-design of the "expanded didactic analysis model" and as a consequence of the multi-disciplinary research team co-authoring this manuscript, the need for a concretion of the indicators which are mobilized in a curricular-integration proposal arises. Taking the previous work of J. Torres as a reference [16], we define the following indicators, which might be checked in order to validate a curricular integration proposal:

- Establishing connections between disciplines: This item aims to assess the need for mobilizing curricular knowledge from different curricular disciplines (do the students have to mobilize multi-disciplinary knowledge?). Overcoming this item means that the problem is not being solved from a "split" perception of the knowledge, but invites the student to interconnect concepts from different curricular disciplines.
- Innovative teaching-learning experience: A meaningful experience is strongly related to the procedures and strategies involved during the problem-solving practice. In this regard, the experience should mean an attractive challenge, showing clear differences with traditional problems and pushing the student to investigate new strategies to solve the problem (does the problem involve mechanical or standardized strategies?).
- Motivation: The emotional dimension of problem-solving situations should not be neglected. Therefore, this item should be used to take into account the way in which "players" are living the experience. Emotions and attitudes have a meaningful impact on the consecution of curricular objectives, and have a strong influence on determining the success/failure ratio of a problem-solving situation (does the problem foster the implication, curiosity, and motivation of the student?).
- Critical thinking: An integrated problem-solving situation should be designed to stimulate reasoning and strategy development. Activities presenting a "single way" for reasoning should be avoided, so that students have to make questions, develop strategies, and provide answers in an autonomous way (does the problem provide multiple perspectives for its solution?).
- Team working: An integrated problem-based approach should prioritize the sharing of ideas. This should mean a coordination to reach a consensus answer to the problem, so that different points of view converge by promoting discussion and reflection (does the situation promote the sharing of ideas?).

The previously mentioned items might be useful to establish and design a model to study curricular integration approaches. These items emerge as a consequence of the adaptation of Font's model [34] to fit with a curricular integration perspective. It can be concluded that the effort made by CS#4 has been fruitful not only from the formative point of view, but from the research output achieved. The similarity of the presented items with that of the original Font's model is a consequence of the common roots of the music and mathematical knowledge [53].

4.3. Result 2: Extract of the Student's Proposal

The complete and original proposal made by CS#4 is stored at RODIN [47], which is the institutional repository of Research and Learning Objects of our university. A translated, reduced version is available as supplementary material #1 for this manuscript. However, an extract of the proposal is presented here so a view of its formative potential (for both the student who was designing the proposal and the schoolchild playing the game) can be assessed.

The original proposal is composed of three "missions" to be accomplished by the players during a 45 min EER experience. As the complete experience could not be reproduced here, a view of one of the activities is presented. In this activity, players can use an audio-recorded message to deduce the path followed by a thief. The corresponding audio track is available as supplementary material #2 for this manuscript. Using the audio, the schoolchild should track the thief's path on a map (whose construction was the final activity of the previous mission). Once the path is drawn on the map, a combination of directions arises. Such a combination shall be coded in "arrows" and the code shall be introduced in a padlock to proceed to the next activity (see Figure 3).

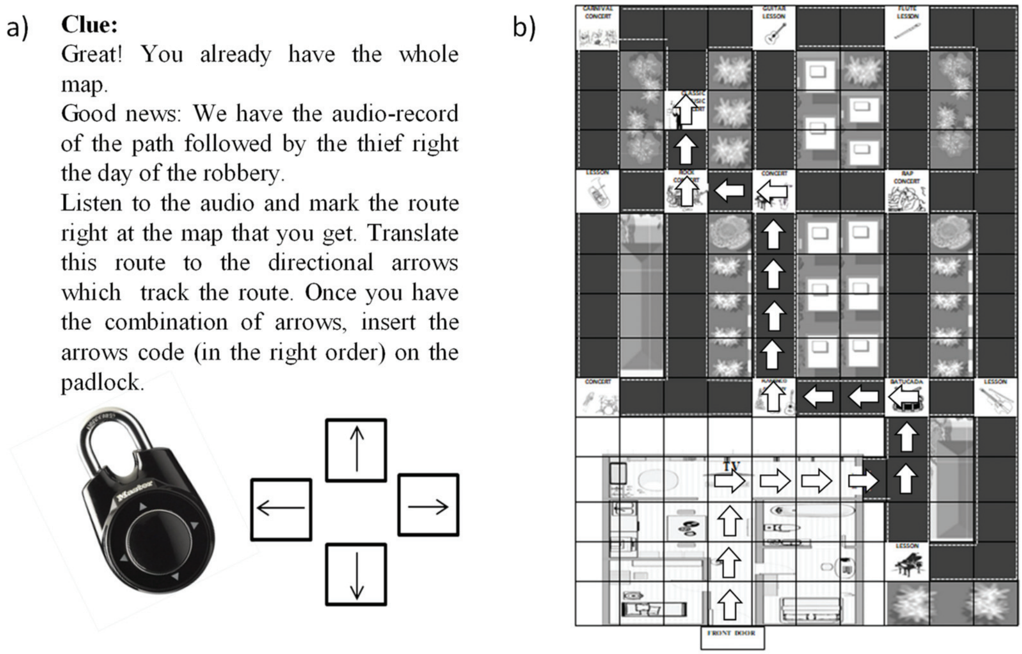


Figure 3. Extract of the student's proposal. This figure corresponds to the clue (**a**) that should be used to solve a problem combining a map (**b**) and an audio source (Supplementary Material #2). By listening to the audio, students should track the path of a thief in the provided map. The translation of such path to "directional arrows" could be then introduced on the directional padlock, opening the next mission of the EER. Directional arrows which code the mentioned path are superimposed to the original map (white arrows, not provided by the student-player).

4.4. Discussion 2: Didactic Suitability of the Proposal

In the particular case of an EER, the curricular content as well as the tools, guides, and supports have to fit with the specific characteristics of the course and school (in order to preserve the flow state). Furthermore, other key elements should be considered when analyzing the didactic suitability of a proposal. In this section, a didactic suitability analysis of the student's proposal is carried out, according to literature [50].

4.4.1. Epistemic Suitability

Epistemic suitability aims to evaluate the implementation of institutional knowledge. From the point of view of the mathematic-related competencies, knowledge and mathematical procedures mobilized on the EER shall be considered "good mathematics" (which is useful in daily life). We consider that this item is fulfilled due to the agreement with the on-service teachers of the school. Indeed, the curricular topic (spatial-related knowledge and spatial orientation) was specifically chosen for its direct application. Concerning the music-related competencies, the knowledge and procedures mobilized in the EER refer to the active audition of sound fragments, as well as to the visual and timbral-auditory identification of different musical instruments. The latter means a concrete curricular application focused on the musical experience, an approach that should be meaningful for the students' integral development.

4.4.2. Cognitive Suitability

The way in which the activities are distributed throughout the formative process is also an item to be considered on the assessment of the didactic suitability of a proposal. The designed proposal was developed in the frame of a conventional course and in agreement with the CEIP, so that the knowledge to be used in the room should be at a reasonable distance to what the students already knew. This is to ensure that cognitive conflicts, induced by cognitive limitations right in the moment of the experience, are overcome through experimentation and peer-to-peer discussion.

In the particular case of mathematic concepts mobilized in this proposal, the concepts are well fitting to those presented in literature [54], as part of the NTCM standards [41]. In the particular case in this proposal, the mathematic concepts can be listed as: Itinerary description and coding, itinerary building and interpretation, describing positions and displacements, representing positions and displacements in maps, etc. Musical concepts mobilized in this proposal fit well with the established standards, being interrelated with the mathematic concepts. Such interrelation is concreted in the active audition and the fragmented sound story which contributes to the identification of the itinerary. To build the corresponding itinerary, musical instrument timbral differentiation and different musical style fragments are correlated to the different locations and displacements annotated on the schematic map.

4.4.3. Media Suitability

Here, the grade of adequacy of the materials and tools provided is discussed. In the proposed experience, the audio, speaker, paper, pencil, maps, padlock, radio communication, etc. are provided to the student-players. Such resources may help solve the problem by applying different strategies. Concerning the use of the tools, from a mathematic point of view, the provided resources ease the establishment of the code by providing a "squared pattern" on the map (see Figure 3b), which clarifies the possible paths, locations, and displacements. However, there are some aspects which may induce confusion. Particularly, the moment in which each "turn to the left/right" has to be made, may induce some confusions (see Figure 4). To solve this, a token/model of the thief could be provided, fixing its original position so that no mistakes on the final code are induced (note that both final codes are similar, differing on the starting position). Therefore, extrinsic difficulties could be presented on the experience, induced by the misinterpretation of the provided tools.

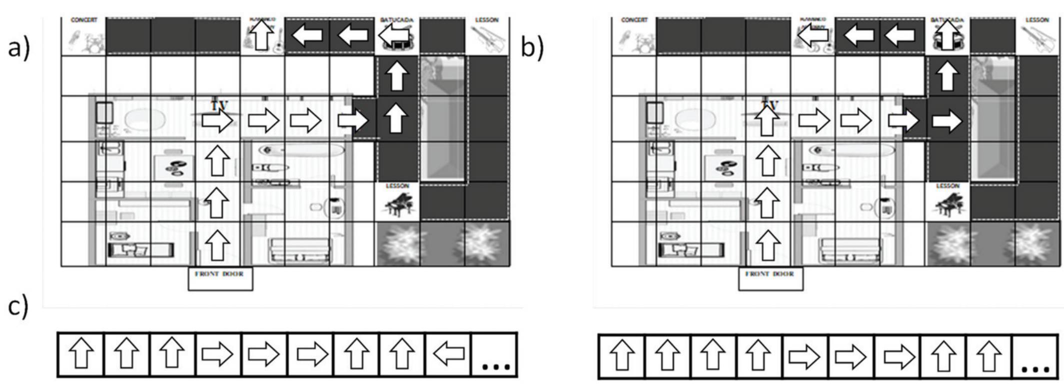


Figure 4. Two possible answers for the proposed activity (Figure 3). Solution (**a**) will open the padlock, while solution (**b**) will be considered as a wrong answer. (**c**) Shows the different codes obtained.

Concerning the musical resources used in the proposal, students would use a speaker to listen to the sound-story. Auditory and visual tools (which are the speaker and schematic maps) should provide enough support to solve the activity. The provided sound story can be reproduced on demand. Again, there is a complementary music-to-mathematics relation so that auditory and visual tools are meaningfully connected.

4.4.4. Interactional Suitability

Interactional suitability is the grade in which the activity allows identifying and solving semiotic conflicts by negotiating meanings. The presented proposal aims for peer-to- peer discussions since the experience is designed for five simultaneous players, which should negotiate mathematical terms such as “left”, “right”, “turn over”, “in front of” or “advance”. Relative positions and displacements must be coded in order to accomplish the activity, so the different perspectives of the map may induce discussions among players. This would require a negotiation about “which one is the right perspective” in order to reach a consensus on the code to be introduced on the padlock.

In the proposed EER, musical aspects are fully related and connected to the mathematical aspects. The EER requires the recognition of sound sequences in the sound story which determines the displacements in the schematic map in Figure 3 (the appropriate sequence of sounds-displacements will provide the code to the next activity of the EER). The potential interactional conflicts should be addressed by negotiation and discussion in a way that evidences auditory skills and the musical background of the students as a fundamental part of the activity, which are needed to accomplish the mission.

4.4.5. Emotional Suitability

The grade of motivation and interest of the students during the formative process should also be assessed. We consider that the proposed experience has an optimum degree of emotional suitability due to the originality of the proposal, the multi-disciplinary approach, and the game-based-learning perspective. However, as no implementation of the proposal was possible (due to the COVID-19 pandemic), this item could not be properly assessed. Even so, previous experiences designed and implemented by students in the frame of the mentoring program [27] provide enough evidence of meaningful emotional suitability of EERs.

4.4.6. Ecologic Suitability

Finally, the grade of fitting of the experience to the educational project of the school should also be considered. In this regard, we consider that ecologic suitability is quite appropriate since the topic, concepts, tools, and moment of implementation were negotiated with the on-service teacher due to the co-design approach.

4.5. Professional Development Analysis

A brief analysis of the professional development reached by CS#4 during the experience is presented in this section. The “16 roles model” [55] (which is based on the discussion presented by Azcárate in literature [56]) is used here to perform the analysis. Of course, there are deeper and more complex models (such as MTSK model [57], for example). However, such models are approachless for those not specifically instructed on the model. The selected model was chosen for its simplicity, comprehensibility, and accessibility (even for non-specialized researchers), while being a validated model useful for the research in didactic of the mathematics. The selected model is schematically presented in Figure 5. According to the 16 role models, the presented experience fits with the 11 roles of the teacher, which means that the complete experience has mobilized several professional roles and skills:

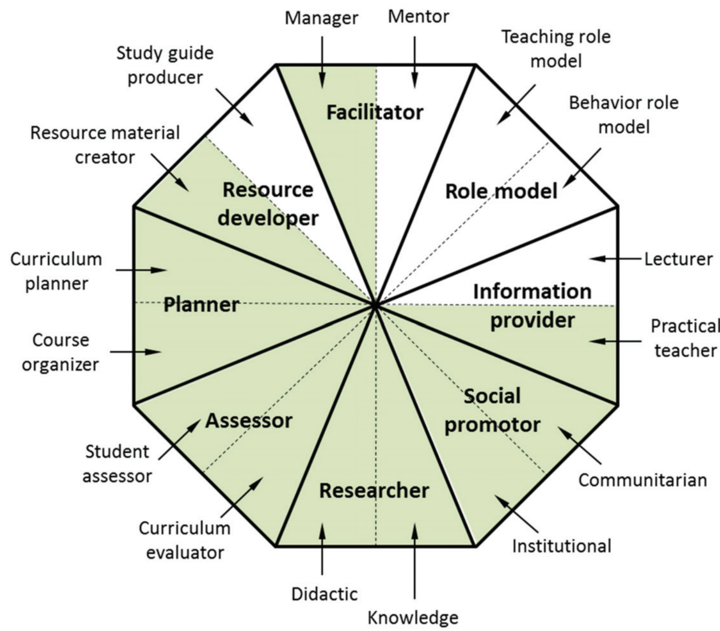


Figure 5. Role model used to analyze the professional development in this study. Roles mobilized during the experience have been filled in green.

- Developing an EER implies scheduling activities such as the solving time ("planner" role), as well as designing specific material ("resource developer" role).
- A proper design of the activities included in the EER should be accompanied by an analysis of the possible difficulties which may emerge during the experience ("practical teacher" role). Such activities should be designed to allow schoolchildren for an autonomous solution of the problem, displacing the "center of gravity" from the teacher to the student ("manager" role).
- A problem-based learning approach, which is in the base of serious game-based learning methodologies, involves a meaningful period of supervised self-formation, guided through the provided literature, seminars, and meetings. This stage requires months of formation on PBL-GBL methodologies (related to the "researcher" role). In this regard, the supplementary material including the corresponding research, carried out by the student, can be consulted in literature [47].
- Students are designing EERs in coordination with on-service teachers, as a result, the university and school worlds get approached. Familiars are updated about the content of the project (their child will be video-recorded, so an authorization is required), and are invited to follow the evolution of the project. As a result, the "social promotor" role is developed.
- Finally, students have to consider the curricula during the design of the EER. Once designed, the implementation of the EER is video-recorded and this resource is used to evaluate not only the schoolchild knowledge, but the EER performance itself (connecting with the "assessor" role).

The previously described roles are strongly related with the development of professional competencies, which are developed by integrating and transforming the knowledge acquired during professional experiences, solving real problems, and mobilizing didactic-professional knowledge (according to literature [58], see schematic in Figure 6).

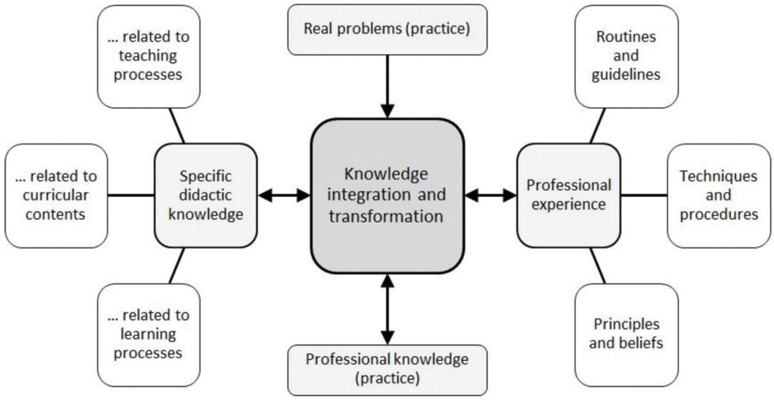


Figure 6. Schematic of the elaboration of "practice" professional knowledge (adapted from [53]).

Students develop different professional competencies depending on the moment of the experience: (i) Professional competencies needed while implementing EERs:

- Meet and promote interaction processes, cooperation strategies, and team-working.
- Promote educational (to an active and democratic citizenship) and scientific values, fostering the democratic education of citizens and the practice of critical social thinking.
- To identify, report, and collaborate in the treatment of learning difficulties by identifying and planning the resolution of educational situations that affect students with different abilities and different learning rates.
- Evaluate the curriculum content and teaching resources and its influence on the promotion of basic skills in students.
- Communicative and interactional skills.

Additionally, (ii) professional competencies needed while developing EERs:

- Meet the curriculum.
- Understand the basic principles and fundamental laws of the experimental, social, and exact sciences.
- Develop and evaluate appropriate teaching resources able to promote the acquisition of basic skills in students.
- Problem-solving skills.
- Establishing connections among subjects and developing a problem-solving perspective strongly related to real problems.

4.6. CS#4 Achievements: A Love-Hate Tale

While we have presented several data concerning the whole students' "designer team", this manuscript focuses on the formative process of one of the students (CS#4) due to her initial "math-phobia". To provide evidences of the evolution on the perceptions of CS#4, Table 2 summarizes some answers to questionnaires. Such questionnaires were provided to CS#4 prior to the delivery of the core didactic of the mathematic subjects of the conventional curriculum and once the core subjects and additional "specific formation" was delivered. Meaningful changes in the perception of this student are evidenced. Particularly, her vision of the mathematic knowledge seems to have evolved from an algorithmic-centered perspective to a perspective where reasoning, strategy development, and hypothesis/discussion dynamics are much more relevant. Comparing the responses "before and after" the whole experience is delivered, we observe that:

- CS#4 relation with the mathematical discipline is meaningfully improved (her rating rises from 2 to 4).

- Her perceived importance of establishing connections to other curricular subjects and topics has been meaningfully increased (rating rises from 3 to 5).
- The student has gained self-confidence and she feels more comfortable about her didactic and mathematical knowledge when referring to teach in primary education schools. This is particularly important due to the motivations presented in the Introduction (see Figure 1).
- Her perception about the usefulness of the mathematical knowledge in real life situations, which was already high, has also been increased.
- The relative importance attributed to "making operations" decreased from 5 to 4. Therefore, she seems to have understood that "knowing mathematics" is much more than "making operations".
- In connection to the previous point, her perception of the importance of "mathematically reasoning" and "developing strategies" rise from 3 to 5 in both items. This constitutes a major evidence of a meaningful change of her perception of the discipline.
- In addition, the importance attributed to the use of "algorithms provided" and "tools provided" are inverted: "Tools provided" items rise from 3 to 5, while "algorithms provided" items decrease from 5 to 3. This is also a meaningful change in her perception of the discipline, since the mathematical knowledge now seems to be a much more "applied" version than before.
- Finally, a dramatic increase in the role of peer-to-peer discussions is evidenced (the score rises from 2 to 5). This is probably due to her experience when implementing other EERs [27], where peer-to-peer discussions are evidenced to contribute to horizontal mathematization.

We can summarize that, while some insecurities still remain (concerning her perceived ability to conduct mathematical lessons), connections to other subjects and areas are more relevant for her, so that the experience seems to have fostered her capacity to "identify mathematical knowledge" in a wide variety of situations.

On the other hand, her perception about the applicability of mathematical knowledge has gained some relevance, making emphasis on connections among curricular areas and application of the knowledge in real-life scenarios.

Table 2. Extract of questionnaires provided to cooperating student #4 (CS#4) and a comparison of her responses with other students before and after the experience.

Question	Before					After				
What do you understand by "knowing mathematics"?	Problem-solving skills					Reflection and justification based on mathematics arguments. Strategy building.				
What is the importance of the emotional factors when teaching mathematics?	Determining the interest for the subject					Determining interest and attitude to explore mathematics				
What is mathematic knowledge useful for?	Some aspects of the mathematics are useful (solving operations), while other are not useful in real life					Building critical and analytical thinking				
Rate this questions (1–5)	**Before**					**After**				
What is your relation to the mathematical discipline?	3	3	4	2	4	4	4	5	4	4
What is the importance of establishing connections to other subjects?	2	3	5	3	3	4	3	5	5	4
Do you feel well prepared to conduct mathematics lessons?	2	2	3	3	3	3	4	5	4	4
I have enough mathematical knowledge to teach in primary education schools	2	3	4	4	3	3	3	4	4	4

Table 2. *Cont.*

I have enough didactic knowledge to teach in primary education schools		3	3	4	3	4	4	4	5	4	4
Mathematics are only useful if applicable to real-life problems		4	3	5	4	5	4	5	5	5	5
The role of the teacher is a key factor that may determine the relation with the mathematics of my future students		5	5	5	5	4	5	5	5	5	5
Rate the importance of	Making operations	5	5	4	5	5	4	4	4	4	5
	Reasoning	2	3	4	3	3	4	4	5	5	4
	Developing strategies	2	2	3	3	3	3	4	5	5	4
	Tools provided	1	2	2	3	3	3	3	4	5	4
	Algorithms provided	5	4	5	5	4	4	3	3	3	3
	Discussions	1	2	2	3	1	3	3	4	5	4
Cooperating student		**#1**	**#2**	**#3**	**#4**	**#5**	**#1**	**#2**	**#3**	**#4**	**#5**

4.7. Students' Achievents: Educational Goals

The whole group of students was invited to develop their final degree thesis to complete the whole formative experience. This was a challenge for most of these students. Indeed, the participant students perceive the mentoring program as an opportunity to improve their mathematical skills, but most of them felt some anxiety with the idea of developing the final degree thesis focusing on the mathematical knowledge. The final degree thesis should consist of a 50–60-page document summarizing their experience, showing the theoretical background and evidencing a learning process. Furthermore, it should be defended on a committee and was mandatory to obtain the teacher's degree. Figure 7 shows a radar plot of the evaluation of professional skills corresponding to all the participant students. Professional didactic-mathematical knowledge was evaluated using the tools and tasks presented in Table 1. To the authors' consideration, the final degree thesis committee reports are a key aspect fact to be considered for the evaluation of the performance of the whole experience, thus it is included in Figure 7.

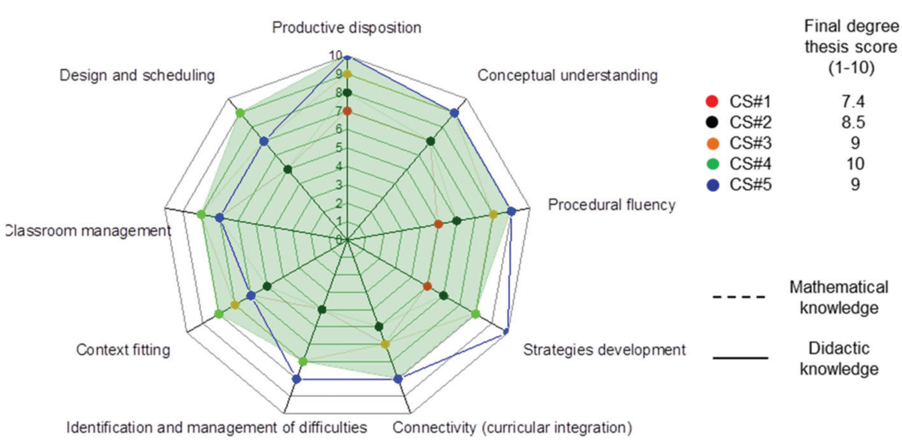


Figure 7. Radar plot of the evaluation of professional didactic-mathematical knowledge and final degree thesis score of the participant students. The CS#4 plot is filled in green to highlight her specific performance.

Examining Figure 7, it can be observed that students succeed on all of the items related to mathematical knowledge. Concerning the didactic knowledge, some students still fail in identifying and managing the schoolchildren difficulties. While the size of the sample is too small to provide fully reliable conclusions, Table 2 and Figure 7 provide enough evidences of a positive evolution on both: Didactic and mathematical knowledge of participant students.

- Mathematical knowledge:
  - Conceptual understanding aims to check the global domain of the different mathematical concepts and its different interpretations. This is what is conventionally said to "know mathematics" in its most traditional way. Data presented in Figure 7 show that all students are presenting good/very good conceptual understanding.
  - Procedural fluency is related to the ability to efficiently use the mathematical concepts, regarding the precision and flexibility. Figure 7 shows meaningful differences among students, which can be explained by a different level of mathematical practice.
  - Strategies development is another item which shows meaningful differences among students. This item is related to the ability to identify a variety of perspectives to solve a problem, which should lead to the choice of an optimum and viable strategy. Most of the students still show a wide margin for improvement in this field.
- Didactic knowledge:
  - The ability to connect mathematical knowledge to real-life situations is taken into account in the "connectivity" item. This item is particularly important in a curricular integration approach. It can be observed that all the participant students' score above 5/10, but some students still show limited ability to re-contextualize the mathematical knowledge.
  - The ability to identify and manage schoolchildren's difficulties is closely related to students' self-abilities to overcome their own difficulties. This may explain the obtained result, with two groups of students clearly differenced. While students 3–4-5 show a remarkable ability in this field, students 1–2 fail in identifying schoolchildren's difficulties, which is coherent with the results obtained in the "mathematical knowledge" evaluation.
  - Context fitting and didactic transpositions are key professional skills. Teaching has to be adapted to the specific knowledge of the learner. Indeed, teachers should explore the previous ideas of the schoolchildren prior to the design of a lesson. In our experience, students' ability to fit to the context could be considered as "good" for all participants.
  - Classroom management skill is the best scored skill in average. It is related to the ability to manage conflicts, structure schoolchildren, and coordinate the learning process in a learning-teaching experience.
  - Design and scheduling ability is related to the "context fitting ability", since no good design can be performed without context. Scheduling a proper sequence of problems or ideas (even in a 45-min escape room) is a key aspect to be considered. Figure 7 evidences that, while all students score above 5/10, there is still some margin to improve.
- Finally, productive disposition is not an item directly associated to didactic or mathematical knowledge. However, it is a key feature in every aspect of life (indeed, a good attitude trends to influence a good problem solution). We can state that all participant students show an excellent productive disposition through the whole experience.

This result supports the usefulness of the mentoring program, evidencing that additional and specific didactic-mathematical education may help change the situation exposed in the Introduction (see Figure 1). Finally, authors would like to emphasize that the evolution of the five cooperating students was made by annotations, questionnaires, interviews, and deliverables: These items could not be attached to this manuscript (they are handwritten and/or presented in Spanish language). However, relevant evaluation notes are presented in Table 2 and Figure 7.

5. Conclusions

This manuscript presents and analyzes an extract of a proposal made by one student (a trainee teacher which was part of a five-member group). Such a proposal was designed in the frame of a mentoring program, whose aim was to explore the influence of a specific and additional formation on didactic and mathematical knowledge. Our approach was to "work mathematical concepts based on other curricular disciplines", so that students could use their "favorite topics" to expand their didactic and mathematical knowledge.

As teachers and researchers, the authors' aim was to establish a problem-based-learning approach by applying gamification strategies. Previous results [27] indicate that educational escape rooms can be used to foster cooperation, motivation, and exploration, thus becoming an optimum tool for working mathematic-related content. Therefore, students were invited to design (in cooperation with different schools) educational escape rooms, covering curricular aspects. A co-design strategy with a service-learning perspective allows fitting the escape room design to the real needs of the schoolchild, also stimulating the implication of the participant students in the process.

This study focuses on the formative potential of "co-designing educational escape rooms in a service-learning perspective", evidencing the mobilization of professional skills and knowledge and showing a boost on the importance attributed to "reasoning", "development strategies", and other mathematic-related skills, which were previously perceived as secondary skills when considering the importance of "using algorithms". Furthermore, the mentoring program has been proven as useful for developing students' professional didactic-mathematical knowledge.

Analyzing our original objectives, we consider that: (i) The experience stimulates the capacity to use mathematic knowledge in non-conventional contexts, (ii) the student shows a positive evolution in their relation with the mathematic knowledge, and (iii) mathematical competencies have been meaningfully connected to other disciplines in the frame of an integrated curriculum approach. Therefore, we consider that educational escape rooms are suitable tools to build problem-based situations with an integral curriculum perspective. We also consider that co-designing educational escape rooms fosters the development of trainee teachers' professional skills, mobilizing specific professional didactic-mathematical knowledge.

On the other hand, during the experience accumulated experience (considering the presented manuscript and previously published experiences [27]), we have detected three main obstacles to overcome in order to develop/apply EER. The first is to establish a clear narrative with a strong relation to the problems presented in the EER, so that all activities are narratively connected in a meaningful way. The second is to create connections among subjects, promoting an integrated view of the knowledge. In addition, the third is the design of real and meaningful problems which requires reasoning, experimentation, argumentation, and calculation, overcoming the pen-paper based activities.

During the experience, key didactic-mathematical professional skills were evaluated. In doing so, we have detected specific skills whose development requires special attention in future editions of the mentoring program. Thanks to this perspective, we have detected that the key competencies mobilized by the students during the development process were: (i) Meeting the curriculum, (ii) understanding the basic principles and fundamental laws of the experimental, social, and exact sciences, (iii) developing and evaluating appropriate teaching resources able to promote the acquisition of basic skills in students, (iv) developing problem-solving skills, and (v) establishing connections among subjects and developing a problem-solving perspective strongly related to real problems.

Finally, the 2020 pandemic scenario prevents us from implementing this specific experience. However, other EER experiences have been implemented in the frame of the mentoring program. As a result, we consider that the key competencies mobilized during the application of an EER experience are: (i) Meet and promote interaction processes, cooperation strategies, and team-working, (ii) promote educational and scientific values (for an active and democratic citizenship), fostering the democratic education of citizens and the practice of critical social thinking, (iii) identify, report, and collaborate in the treatment of learning difficulties by identifying and planning the resolution of educational situations that affect students with different abilities and different learning rates, (iv) evaluate the curriculum content and teaching resources and its influence in the promotion of basic skills in students, and (v) communicative and interactional skills.

Future editions of the mentoring program should emphasize on developing specific students' skills. Particularly procedural fluency, strategies development, identification of difficulties, and problem design are skills to be specifically attended. We consider that designing and implementing educational, integrated, problem-based escape rooms constitutes an optimum procedure to expand students' competencies, as well as to explore didactic/mathematic knowledge in a meaningful way. Furthermore, this procedure allows students to explore and grow over their own limitations, while providing a service to local schools.

Supplementary Materials: The following are available online at https://www.mdpi.com/2227-7102/11/3/131/s1.

Author Contributions: Conceptualization, J.C.P.C.; Methodology, J.C.P.C. and P.O.G.; Validation, J.C.P.C. and S.R.G.; Formal Analysis, J.C.P.C.; Investigation, J.C.P.C. and P.O.G.; Resources, P.O.G.; Data Curation, J.C.P.C.; Writing—Original Draft Preparation, J.C.P.C.; Writing—Review & Editing, J.C.P.C.; Visualization, J.C.P.C.; Supervision, J.C.P.C. and S.R.G.; Project Administration, J.C.P.C.; Funding Acquisition, J.C.P.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the grants sol-201900138517-tra of the "2019/20 Teaching innovation projects" of the Cádiz University, and PR2017-013 of the "2017–18 Program to promote and boost research and transfer of the Cadiz University".

Institutional Review Board Statement: All subjects gave their informed consent for inclusion before they participated in the study. Private information (which could be used to identify the participants) is not included in this document. This study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of the GAMIMAT project.

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

Data Availability Statement: Additional supporting data analyzed or generated during the study can be found in: https://www.mdpi.com/2227-7102/10/9/213 (accessed on 16 March 2021).

Acknowledgments: The authors would like to thank the help and collaboration of Pilar Azcárate Goded and José María Cardeñoso Domingo. We would also like to thank the cooperating students: Ana Ruiz, Claudia Macías, Daniel García, and Antonio García. Finally, this experience would not be possible without the collaboration of the CEIPs of the province of Cádiz (particularly that of the CEIP San Juan de Rivera).

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.

References

1. Beane, J. The Middle School: The Natural Home. *Educ. Leadersh.* **1991**, *49*, 9–13.
2. Education GPS—Spain—Student performance (PISA 2018). Available online: https://gpseducation.oecd.org/CountryProfile?primaryCountry=ESP&treshold=10&topic=PI (accessed on 30 November 2020).
3. Instituto Nacional de Evaluación Educativa TEDS-M. *Informe Español. Estudio Internacional Sobre la Formación Inicial en Matemáticas de los Maestros. Análisis Secundario*; Instituto Nacional de Evaluación Educativa TEDS-M: Madrid, Spain, 2013.

4. Anglin, J.M. Develop your own philosophy. *New Teach. Advocate* **1999**, *7*, 3.
5. National Council of Teachers of Mathematics. Available online: https://www.nctm.org/ (accessed on 5 March 2021).
6. National Council of Teachers of Mathematics. *Curriculum and Evaluation Standards for School Mathematics*; National Council of Teachers of Mathematics: Reston, VA, USA, 1989.
7. Mallanda, C.L. The Effects of Changing from a Traditional Mathematics Curriculum to an Integrated Mathematics Curriculum on Student Mathematics Learning in Georgia. *Dissertations* **2011**, *485*, 75–88.
8. Hannover Research. *Supporting an Integrated Mathematics Curriculum*; Hannover Research: Arlington, VA, USA, 2015.
9. Huisman, J.; Adelman, C.; Hsieh, C.-C.; Shams, F.; Wilkins, S. Europe's Bologna process and its impact on global higher education. In *The SAGE Handbook of International Higher Education*; Deardorff, D.K., de Wit, H., Heyl, J.D., Adams, T., Eds.; Sage Publications: Thousand Oaks, CA, USA, 2012; pp. 81–100. ISBN 9781452218397.
10. Musset, P. Initial teacher education and continuing training policies in a comparative perspective. *OECD Educ. Work. Pap.* **2010**, *48*, 1–47.
11. Ellis, A.K.; Stuen, C.J. *The Interdisciplinary Curriculum*; Eye On Education: Larchmont, NY, USA, 1998; ISBN 1883001552.
12. Lake, K. *Integrated Curriculum*; Northwest Regional Education Laboratory: Washington, DC, USA, 1993.
13. Harden, R.M. The integration ladder: A tool for curriculum planning and evaluation. *Med. Educ.* **2000**, *34*, 551–557. [PubMed]
14. Senk, S.L.; Thompson, D.R. *Standards-Based School Mathematics Curricula: What are They? What Do Students Learn?* Lawrence Erlbaum Associates: Mahwah, NJ, USA, 2002.
15. Usiskin, Z. The integration of the school mathematics curriculum in the United States: History and Meaning. In *Integrated Mathematics Choices and Challenges*; National Council of Teachers of Mathematics: Reston, VA, USA, 2003; pp. 13–32.
16. Torres, J. *Globalización e Interdisciplinariedad: El curriculum Integrado*; Morata: Madrid, Spain, 2012; ISBN 9788471123725.
17. Viladot, L.; Hilton, C.; Casals, A.; Saunders, J.; Carrillo, C.; Henley, J.; González-Martín, C.; Prat, M.; Welch, G. The integration of music and mathematics education in Catalonia and England: Perspectives on theory and practice. *Music Educ. Res.* **2018**, *20*, 71–82. [CrossRef]
18. Colwell, C.M. Integration of Music and Core Academic Objectives in the K–12 Curriculum. *Updat. Appl. Res. Music Educ.* **2008**, *26*, 33–41. [CrossRef]
19. Gómez Barreto, I.M.; Lledó Carreres, A.; Perandones González, T.M.; Herrera Torres, L. El empoderamiento como estrategia de éxito en la formación inicial del profesorado. *Int. J. Dev. Educ. Psychol. Rev. INFAD Psicol.* **2017**, *7*, 151160. [CrossRef]
20. Piñero Charlo, J.C.; Costado Dios, M.T. Codiseño de problemas geométricos apoyados en TIC: Estudio de un caso con estudiantes de maestros bajo un modelo de aprendizaje mixto on a blended learning module. *Edutec. Rev. Electrónica Tecnol. Educ.* **2020**, *74*, 94–113.
21. González, A.A.; Roig, A.E.; Suari, N.O.; Juanola, M.M. Aprendizaje-servicio y codiseño en la formación de maestros: Vías de integración de las experiencias y perspectivas de los estudiantes. *Bordon* **2016**, *68*, 169–183. [CrossRef]
22. Martin, J.; Spader, K.; Jhonson, J. Empower learners. In *13 Principles of Good Learning in Games—Apllied to Teaching*; University of Wisconsin Pressbooks: UW-Madison, WI, USA, 2017.
23. Analysing and supporting the process of co-designing inquiry-based and technology-enhanced learning scenarios in higher education. Available online: https://www.lancaster.ac.uk/fss/organisations/netlc/past/nlc2014/abstracts/pdf/garcia.pdf (accessed on 16 March 2021).
24. Sigmon, R.L. Service-Learning: Three Principles. *Synergist* **1979**, *8*, 9–11.
25. Opazo, H.; Aramburuzabala, P.; Mcilrath, L. Aprendizaje-servicio en la educación superior: Once perspectivas de un movimiento global. *Bordón. Rev. Pedagog.* **2019**, *71*, 5–23. [CrossRef]
26. Piñero, J.C. Análisis sistemático del uso de salas de escape educativas: Estado del arte y perspectivas de futuro. *Espacios* **2019**, *40*, 9.
27. Piñero Charlo, J.C. Educational Escape Rooms as a Tool for Horizontal Mathematization: Learning Process Evidence. *Educ. Sci.* **2020**, *10*, 213. [CrossRef]
28. Edo, M.; Baeza, M.; Deulofeu, J.; Badillo, E. Estudio del paralelismo entre las fases de resolución de un juego y las fases de resolución de un problema. *Union Rev. Iberoam. Educ. Matemática* **2008**, *14*, 61–75.
29. Carmona, E.; Cardeñoso, J.M. Situaciones basadas en juegos de mesa para atender la elaboración del conocimiento matematico escolar. *Épsilon* **2019**, *101*, 7–30.
30. Rott, B. The different mathematics performances in PISA 2012 and a curricula comparison: Enriching the comparison by an analysis of the role of problem solving in intended learning processes. *Math. Educ. Res. J.* **2019**, *31*, 175–195.
31. Kelly, A.E.; Lesh, R.A.; Baek, J.Y. *Handbook of Design Research in Methods in Education. Innovations in Science, Technology, Engineering, and Mathematics Learning and Teaching*; Routledge: New York, UK, USA, 2008.
32. de Benito Crosetti, B.; Salinas Ibáñez, J.M. La Investigación Basada en Diseño en Tecnología Educativa. *Rev. Interuniv. Investig. Tecnol. Educ.* **2012**, *0*, 44–59. [CrossRef]
33. Brousseau, G. Fondements et méthodes de la didactiques des mathématiques. *Rech. Didact. Mathématiques* **1986**, *7*, 33–115.
34. Didactic Engineering as Design-Based Research in Education. Available online: https://www.mathematik.uni-dortmund.de/~{}erme/index.php?slab=cerme-proceedings (accessed on 16 March 2021).
35. Brousseau, B. *Theory of Didactical Situations in Mathematics*; Kluwer: Dordrecht, The Netherlands, 1997.
36. Walsh, A. *Making Escape Rooms for Educational Purposes: A Workbook*; Innovative Libraries: Huddersfield, UK, 2017.

37. Nicholson, S. Creating engaging escape rooms for the classroom. *Child. Educ.* **2018**, *94*, 44–49. [CrossRef]
38. Hermanns, M.; Deal, B.; Campbell, A.M.; Hillhouse, S.; Opella, J.B.; Faigle, C.; Campbell IV, R.H. Using an "Escape Room" toolbox approach to enhance pharmacology education. *J. Nurs. Educ. Pract.* **2018**, *8*, 89. [CrossRef]
39. Ma, J.-P.; Chuang, M.-H.; Lin, R. An innovated design of ER box by STEAM. In *Proceedings of the Cross-Cultural Design: Applications in Cultural Heritage, Creativity and Social Development*; Rau, P.-L.P., Ed.; Springer: Las Vegas, NV, USA, 2018; Volume 2, pp. 70–79.
40. Ask Why: Creating a Better Player Experience through Environmental Storytelling and Consistency in Escape Room Design. Available online: https://meaningfulplay.msu.edu/proceedings2016/ (accessed on 16 March 2021).
41. *Principles and Standards for School Mathematics*; The National Council of Teachers of Mathematics: Reston, VA, USA, 2000; ISBN 0-87353-480-8.
42. Van de Walle, J.A.; Karp, K.S.; Williams, B.; Jennifer, M. *Elementary and Middle School Mathematics: Teaching Developmentally*, 8th ed.; Pearson, Ed.; Student Value Edition: New York, NY, USA, 2013.
43. Rico, L. El método del Análisis Didáctico. *Union Rev. Iberoam. Educ. Matemática* **2013**, *33*, 11–27.
44. Font, V.; Planas, N.; Godino, J.D. Modelo para el análisis didáctico en educación matemática. *Infanc. Aprendiz. J. Study Educ. Dev.* **2010**, *33*, 89–105. [CrossRef]
45. López-Lozano, L.; Solís, E.; Azcárate, P. Evolution of Ideas About Assessment in Science: Incidence of a Formative Process. *Res. Sci. Educ.* **2018**, *48*, 915–937. [CrossRef]
46. Lopes, C.; Jaramillo, D. *Escenas De La Insubordinación Creativa En Las Investigaciones En Educación Matemáticas En Contextos De Habla Española*; Distribuido por Lulu Press, Inc.: Raleigh, NC, USA, 2017; p. 128.
47. Ortega García, P. Análisis de Entornos Gamificados Como Recursos de Integración Curricular. Una Experiencia músico Matemática. Available online: https://rodin.uca.es/handle/10498/23498 (accessed on 20 January 2021).
48. Rusinek, G. Aprendizaje musical significativo. *Rev. Electron. Complut. Investig. Music.* **2004**, *1*, 1–16.
49. Zaragozá, J.L. Aprendizaje significativo de los procedimientos musicales. In *Didáctica de la Música en la Educación Secundaria. Competencias Docentes y Aprendizaje.*; Graó: Barcelona, Spain, 2009; pp. 179–180.
50. Godino, J.D.; Bencomo, D.; Font, V.; Wilhelmi, M.R. Análisis y valoración de la idoneidad didáctica de procesos de estudio de las matemáticas. *Paradigma* **2006**, *27*, 221–252.
51. Schafer, R.M. *The Tuning of the World*; Rando House: New York, NY, USA, 1977; ISBN 0-394-40966-3.
52. Schafer, R.M. *El Paisaje Sonoro y la Afinación del Mundo*; Intermedio: Barcelona, Spain, 2013.
53. Casals Ibánez, A.; Carrillo Aguilera, C.; Gonzalez-Martín, C. La música también cuenta: Combinando matemáticas y música en el aula. *Rev. Electrón. LEEME List. Electrón. Eur. Música Educ.* **2014**, *34*, 1–17.
54. Rigal, R. *Motricidad Humana: Fundamentos y Aplicaciones Pedagógicas*; Pila Teleñ.: Madrid, Spain, 1987; ISBN 84-85514-59-9.
55. Piñero, J.C. Modelando los diferentes roles del docente en la educación matemática moderna. *Espacios* **2020**, *41*, 301–317.
56. Azcárate Goded, P. *El Conocimiento Profesional Didáctico-Matemático*; Servicio de publicaciones de la Universidad de Cádiz: Cádiz, Spain, 2001; ISBN 84-7786-939-1.
57. Muñoz-Catalán, M.C.; Contreras, L.C.; Carrillo, J.; Rojas, N.; Montes, M.Á.; Climent, N. Conocimiento Especializado del Profesor de Matemáticas (MTSK): Un modelo analítico para el estudio del conocimiento del profesor de matemáticas. *La Gac. la Real Soc. Matemática Española* **2015**, *18*, 1801–1817.
58. Azcárate Goded, P. La formación inicial del profesor de matemáticas: Análisis desde la perspectiva del conocimiento práctico profesional. *Rev. Interuniv. Form. Profr.* **1998**, *32*, 129–142.

education sciences

MDPI

Review

Escape Rooms in STEM Teaching and Learning—Prospective Field or Declining Trend? A Literature Review

Chantal Lathwesen and Nadja Belova *

Department of Chemistry Education, University of Bremen, 28359 Bremen, Germany; c.lathwesen@uni-bremen.de
* Correspondence: n.belova@uni-bremen.de

Abstract: In the last decade, game-based learning has received growing attention in educational contexts in general and science education in particular. A recent game trend, which has also found its way into STEM classrooms, is escape rooms. In this type of game, players have to work through several puzzles to achieve a specific goal (mostly to escape from an actual room). We conducted a systematic literature review to find out whether the "market" for such games is already saturated or if there is still potential for further development. After searching the common databases (ERIC, Web of Science, and Google Scholar, as well as the German database FIS Bildung), we analyzed 93 journal articles, book chapters, and conference papers in English and German from the following domains: chemistry, physics, biology, mathematics, computer science, general science (interdisciplinary), environmental science, and medicine. We selected the ones that targeted a specific educational level (primary, secondary or tertiary education) and were designed for formal educational settings. It transpired that there is a need for more easily adaptable escape rooms as well as for more empirical evidence on their actual effects.

Keywords: gamification; escape room; review

Citation: Lathwesen, C.; Belova, N. Escape Rooms in STEM Teaching and Learning—Prospective Field or Declining Trend? A Literature Review. *Educ. Sci.* **2021**, *11*, 308. https://doi.org/10.3390/educsci11060308

Academic Editors: José Carlos Piñero Charlo, María Teresa Costado Dios, Enrique Carmona Medeiro and Fernando Lloret

Received: 28 May 2021
Accepted: 16 June 2021
Published: 21 June 2021

1. Introduction

Gaming is a universal phenomenon. Baby animals and human children play games in which they test and get to know their bodies and the surrounding world. They play just for the sake of playing—without knowing anything about the game's features or effects. The concept of playing is a fundamental part of human activity and can be found in various forms in all cultures and societies around the world [1]. When it comes to the effects of playing, prominent psychologists and educational researchers such as Montessori and Piaget have acknowledged the value of playing for the development of children over hundreds of years [2]. Vygotsky (1980) described games as providing opportunities for children to experience scenarios they are not yet able to live through in real life [3]. Thus, the importance of games for one's development has led to the inclusion of game-based settings for learning purposes [4] both in lower and upper secondary as well as in higher education. When studying the extensive literature on gamification and game-based learning it becomes obvious that the educational goals described in the literature are quite diverse, ranging from the promotion of content knowledge over motivation towards fostering collaboration and argumentation skills [5]. On the other hand, the evidence on actual learning outcomes fostered by games remains quite inconsistent [6]. Nevertheless, there undoubtedly are positive effects of educational games, such as an increase of motivation, as well as some quality criteria which can help to create games which are not only entertaining but also promote specific educational goals [7].

The literature indicates that game-based learning has received increasing attention—some researchers even consider educational games to be one of the biggest "hypes" of the last decade in the educational context [8] (p. 5). Game-based learning (GBL) [9] embraces activities which employ game mechanics for learning purposes, which leads us to the concept of gamification. Gamification is commonly defined as the changing of processes that are not games through the implementation of a game or at least elements of one [10]. Here, game mechanics are explicitly used to follow concrete educational goals and solve specific problems [4].

Commonly mentioned elements for gamification in learning and education are story, dynamics, mechanics, collaboration, goal-oriented design, a set of rules, and technology [4,11]—some of these are mostly applicable to digital games. However, this does not mean that specific elements *must* be used for gamification in learning and education, and using many gamification elements does not ensure more effective gamification or better results [12]. The challenge for educators is to choose necessary gamification elements to create an integrated solution that facilitates learning and education [4]. Based on the research findings available so far, Tsekleves et al., (2016) as well as Kim et al., (2018) developed several quality criteria that educational games should possess to increase the likelihood of motivational as well as educational outcomes. Games in educational frameworks should, among other things, be aligned with the curriculum, have clear learning goals like progression or repetition, be interactive, and contain aspects which can be used for assessment and feedback purposes thus allowing students to check their own progress [4,7].

Whoever plays steps out of their everyday experience and in a sense overrides it to immerse themselves in a game world. This phenomenon is addressed in the concept of the "flow theory" [13]. Here, the state of "flow" is described as a total absorption by a task which is both challenging and enjoyable. Such a totally immersive recent game trend is the so-called escape room. Escape rooms are a relatively new game concept that has been gaining popularity since around 2012 [14]. According to Nicholson (2015), an escape room is a physical adventure game in which the players have to work through various puzzles and tasks in a collaborative manner in order to achieve an overarching goal within a certain time limit [14]. Usually this consists of escaping from one or more rooms. Alternatively, the players must complete a specific task as part of the respective story, such as solving a criminal case or finding a hidden treasure. Before the game begins, the game master informs the players about the rules, the safety instructions, the general process, and the goal of the escape room. If there is a background story, the game master introduces the participants to the game, for example by reading an old diary entry. Then the door of the room is locked and the timer is started. Within the time limit, the players must use the objects they have discovered and decipher clues to solve the puzzles in order to advance in the game. During this time, the game master only acts as an observer and can provide assistance to the group if necessary. The game ends when the time runs out or the group has reached the goal. Over the course of the last decade, the game concept has been constantly further developed, characterized by an increase in the diversity of puzzles, a stronger integration of the story, thematically and technically more complex room design and, more recently, an increase in digitization [15,16]. In addition to physical escape rooms, due to their increasing popularity and the needs of different areas of application, other formats have been developed, including escape books, breakout boxes or home kits, augmented reality or virtual reality escape rooms, and digital escape games [17].

An integral part of escape rooms are puzzles. In commercial escape rooms, a distinction is made between two different types of puzzles: mental and physical puzzles [16]. To solve the first, clues must be discovered, deciphered, and related to each other. This requires cognitive skills and logical thinking. The counterpart to this are physical puzzles or tasks in which real objects or parts of the room have to be moved to find the solution. They are more time-consuming and represent cognitive relief. Both types of puzzles are also used in combination. Despite the variety of possible puzzles, three basic structural components can be identified: a problem, a hidden solution, and a reward [16]. To receive the reward, players must first decipher the puzzle and complete the resulting challenge. Often the solution is already hidden in the puzzle itself. The reward may include new puzzle pieces, clues or objects.

Educational escape rooms represent a creative learning environment that combines formal and informal learning. The game concept is adopted, adapted to the needs of the target group, and linked to the required content-related and process-related skills. Educational escape rooms can be developed for all levels of educational institutions and for a wide variety of topics [18]. One of the primary goals of educational escape rooms is the playful learning of new subject matter and skills as well as the repetition, deepening, and transfer of existing knowledge. In addition, the students are made aware of the effects of their own behavior on themselves and others. Self-confidence, social interaction, and the appreciation of different perspectives are also strengthened [19]. In contrast to the regular tasks of the students, the puzzles in an educational escape room do not contain a directly visible work assignment. This is only implied and must first be developed by the learner with the help of the information [14], representing probably the biggest challenge both for students and teachers (who must step out of their comfort zone to allow such totally open settings). A school implementation of educational escape rooms requires an adaptation of the game concept due to the spatial conditions and the size of the learning group [14]. In contrast to commercial escape rooms, their school equivalent consists in 78.9% of cases of only one room [17]. Consequently, the objects placed in it must be clearly differentiated from the other objects in the room for the pupils, for example by marking them with a logo [20]. Due to the spatial and financial resources of the schools, educational escape rooms should be cost-efficient and spatially reversible, so that the thematic design of the room can only take place in a reduced form [21]. Educational escape rooms have great potential in the school context, regardless of the necessary modifications. The game concept is favored equally by both sexes, takes different learning styles into account, and is particularly suitable for interdisciplinary learning [14]. It is also a motivating, student-centered teaching method in which learners take responsibility for their own learning process. Teachers take on an observing role during the game as a game master. They may only provide support to a certain extent upon request from the pupils. This gives learners the opportunity to independently develop their own ideas, strategies, and solutions, to actively pursue them and, if necessary, to evaluate them. In addition, the pupils are encouraged to use their existing knowledge and skills in an unconventional way to solve the puzzles [19]. Such a student-active, playful approach promotes communication, collaboration, creativity, problem-solving skills, and critical thinking, and can have a positive influence on both the motivation and commitment of the students [16].

The game concept of the escape rooms has gained increasing popularity in the school context in general and in STEM education in particular in recent years. Hardly any science education journal has been without a corresponding article, and the topic has also been present at large international conferences. Thus, the following questions have arisen: what is the current status of the development of STEM-related escape rooms? Which goals do the escape rooms available so far pursue? For which educational levels as well as subjects are escape rooms mostly arranged? So far, no systematic reviews on this topic have been conducted. We analyzed the literature to answer these questions, identify research gaps, and shed light on whether the escape room hype can be considered outdated or whether there is still much to develop and to inquire.

2. Materials and Methods

We conducted literature database searches for the keywords "escape room", "exit game", "escape lab", "escape game", and "breakout" in combination with the STEM education domains science, chemistry, physics, mathematics, and biology education. The search was carried out using the Web of Science and ERIC database, as well as Google Scholar. The databases were selected purposefully. The Web of Science can be considered as the most scholarly based database only including quality journals that fulfill the criteria of being international, peer-reviewed, and recognized within the scientific community. ERIC is a database that also covers publications in education from other sources, like conferences. Google Scholar analyses all publications on the internet and ranks them according to a certain algorithm which mainly depends on their popularity. With this search there is no proof of complete comprehensibility, but it is suggested that there is chance that most of the relevant publications in this topic can be found. We also searched the German database "FIS Bildung" with the same keywords in German which led to 17 hits. The relevant ones (only two in total) had already been found in the international databases due to the fact that they had an English abstract. Thus, this review is limited to publications in English and German. Hits resulting from the combinations of all the above-mentioned keywords totaled 67 in ERIC and 96 in the Web of Science. Google Scholar alone yielded about 2750 hits for the timeframe 2007 and 2021. The search was conducted within the last two weeks of February 2021.

The results of ERIC and the Web of Science were individually analyzed. Prior to this, we formulated inclusion and exclusion criteria for the relevant publications. The inclusion criteria were as follows: we included all versions of educational escape games (tabletop, analogue/digital, books), which took place in a formal educational setting or an informal educational setting with a clear educational objective targeting preschool, primary, secondary, or higher education. The papers all contained a clear description of the setting (content, target group, format, types of puzzles) and were aimed at STEM education (chemistry, biology, physics, math, computer science, health care, medical, nursing and natural sciences in general). We excluded escape games that did not target a specific education level, escape games for informal learning settings such as camps, libraries, or fairs, those without content knowledge goals or content related skills, as well as articles including the keywords in the wrong context (such as breakout rooms within videoconferencing tools). We did not have access to some publications, particularly those from teacher journals.

This led to a total of 37 relevant articles or book chapters. Sixteen additional publications were found by chain-referencing. The first 650 Google Scholar search results were also screened, resulting in 40 additional articles leading to a total of 93 articles making up the foundation of this review. The selected material was first classified according to general criteria: (i) educational domain (primary education, secondary education, tertiary education); and (ii) the topics covered (general science or a specific science/STEM subject such as medicine, chemistry, physics, biology or mathematics). Eight of the suggested settings were intended for primary education, 31 for secondary, and 58 for tertiary education (some of the papers were aimed at both secondary and tertiary levels). Table 1 shows the distribution among the domains. In a second round of categorization, the criteria chosen were learning objectives, theme, group size, format, organization of the puzzles, as well as the role of the teacher/instructor. The issue of reliability was approached by cross-checking of the coding among the authors. The examples selected for illustrating the analysis were chosen with respect to the type of publication: peer-reviewed articles in journals and books were given priority to other types of publications.

Table 1. Overview of the domains of the reviewed escape rooms (one of the publications was intended both for chemistry and physics lessons).

Chemistry	Physics	Biology	Maths	Computer Science	General Science	Environmental Science	Medicine
15	6	4	13	13	5	2	35

3. Results of Educational Escape Rooms in STEM Education

The first very noticeable result of our research was the large number of publications in the field of medicine (see Table 1). Escape rooms seem to be very common especially for the academic training of nurses. When it comes to the STEM domains, most of the examples were found for chemistry education, followed by mathematics and physics. The majority of the suggested games were intended for a collaborative approach with the students being divided into groups (ranging from two to ten people with the average being five students).

Thus, most of the games could be adopted in different class sizes. Only very few settings were aimed at single players. The play time ranged from 15 min to an entire day, with the average duration being 60 min. Analog settings prevail over solely digital ones: 12 chemistry, 2 biology, 1 general science, and all 6 physics escape games included experiments or lab-based activities. Few of the games only involved the simulation experiments in a digital learning environment. Only one escape lab was found. Nearly all escape rooms related to nursing, pharmacy, or medicine were designed as a simulation laboratory, where participants needed to apply lab and clinical skills in a realistic setting. When it came to the types of puzzles involved, crossword puzzles, mathematical tasks, and patterns were often used. The locks were mostly alphabetical or used numbers. The Supplementary Materials for this paper contain a table summarizing the main features of each escape room (e.g., types and number of puzzles, number of players, duration, domain, etc.).

3.1. Educational Escape Rooms in Chemistry Education

As already mentioned, a total of 15 publications were found dealing with escape rooms in secondary and tertiary chemistry education. Only seven of the papers targeted a specific topic and not a combination of several ones. The topics addressed were safety practices in the lab [22], structures and traits of polymers [23], the periodic table [24], the Leblanc process [25], chemical bonding [26], the galvanic cell [27], and the Solvay process [28]. The breakout activity by Nephew and Sunasee (2021) was created for academic institutions in order to make the obligatory safety training more interactive and engaging [22]. The goal of the activity is to open an actual box with three locks. The locks have to be opened using two different codes (numeric and alphabetic) and a key which is hidden in the laboratory. To open the locks, the participants must fulfill three hands-on activities: spill training, emergency response training, as well as waste disposal. In the first activity the players must come up with an order of contents of a spill kit to get rid of a reagent spill. Each content has an assigned letter which in the end makes up the code. This is generally a very common puzzle type for educational escape rooms. The puzzle on emergency response uses fluorescent clue numbers for which you need a black light flashlight to unveil them—such little "playful" elements are also frequently used to make a setting more motivating and challenging. In the escape room on chemical bonding by Ang, Ng and Liew (2020) the first-year general chemistry students had to complete four puzzles (one group of students per puzzle) and a final collaborative puzzle at the end. Each group had to unveil a number for the combination lock. In one of the puzzles, the students had to compare the strengths of different bonds with the help of a model experiment using magnets with the strongest bond being the ionic one. Since "ionic" is spelled with five letters, the hidden number turns out to be five. A rather original idea and a different way of implementing the escape game context comes from Strippel, Schröder, and Sommer (2021) who constructed an escape box. The box is locked and can be opened by constructing a simple galvanic cell with a specific voltage. The voltmeter is connected to a microcomputer which controls the locking mechanism. As soon as the correct voltage is reached, the box is unlocked, and the reward can be retrieved [27].

Two escape rooms covered different aspects from a specific chemical sub-domain, namely analytical chemistry [29] and organic chemistry [30], with the first one being aimed at tertiary education. The setting by Groß and Schumacher (2020) covers main organic chemistry topics from the German secondary school curriculum (alcohols, aldehydes, carboxylic acids, coloring agents, esters) with one puzzle per topic. Thus, this experimental escape room setting can be used to review and consolidate the content knowledge. The context of this proposal is the kidnapping of a chemistry lecturer. The players are supposed to use his labor journal, which is also the structuring element of the game, to decipher the research, track down the kidnapper, and rescue the protagonist [30].

The remaining six proposals combined several thematic aspects from different domains of chemistry. Clapson et al., (2020) designed an escape game in a box format containing four hands-on activities on the following general chemistry topics: thin layer chromatography, buoyancy, density, and a galvanic cell made out of zinc and copper [31]. For instance, in the activity on buoyancy, the learners compared the buoyancy of several pipettes in a plastic bottle filled with water. The correct order of the pipettes leads to a code that unlocks the next puzzle in the box. In the puzzle using a galvanic cell, the microscale cell is used to light up LEDs which are numbered. The numbers can then also be used for the lock. From our point of view, such scenarios can be difficult to adapt by other institutions due to the fact that the exact combination of these contents is needed.

3.2. Educational Escape Rooms in Maths Education

Out of the 13 publications, 7 targeted escape games in secondary math education, followed by primary (4) and tertiary (3). Escape games within the mathematical domain mainly fall into two subcategories: algebra [32] and geometry [33,34]. Algebra-themed escape games dealt with linear and quadratic equations [35], systems of equations [36], slope [37] and polynomials [38]. Geometry-themed escape games mainly addressed trigonometry [39], magnitudes and measurements [33,34,40]. The escape game of Arvanitaki and Skoumpourd (2019) is specially designed to teach students with visual impairment the concept of length [34]. To escape from the museum, they have to calculate and measure the distances between objects with their own steps and find specific measurement tools in the room. Movement and sense of touch are very important for understanding the concept of space and the properties and relationships of the objects in it. Therefore, the escape room is heavily dependent on physical tasks and uses a touchable roadmap and a SmartGuide obstacle detection device, so that students can navigate within the room. Additional topics addressed in the publications include logic [41], rational numbers [42] and calculus and cryptography [43]. Only one escape game does not specify its content-related learning objectives, saying it is based on the third grade curriculum [44]. Students take over the roles of investigators trying to unlock the case and disable the bomb. All teams have to work together and interact with veteran investigators, played by a group of parents. This collaborative approach is possible due to a multi-linear puzzle path, resulting in a meta-puzzle to unlock the bomb case. Small prizes and third grade certificates are handed out as rewards. An interdisciplinary approach can be found for two math escape games. Moura and Santos (2019) designed an analog escape game for the 7th grade combining the subdomain algebra with Portuguese literary work [32]. In "MathEscape", proposed by Galvas and Stascik (2017), students have to steal the solution of an old mathematical problem from the minister‘s office by solving 28 tasks. Nine tasks are non-mathematical, interdisciplinary tasks, such as mixing colors (arts), optic puzzles (physics), space orientation (physical education), comprehension (language), morse code (music), and using the periodic table (chemistry). In addition, mathematical tasks are used to revise and systemize knowledge about linear and quadratic equations. The research focuses on how the game enhances students' attitudes towards mathematics [35]. One digital and three hybrid math escape games were found, consisting of analog puzzles and digital locks [42], programmed puzzles and physical props [41], or augmented elements. Queiruga-Dios et al., (2020) designed an augmented, card-based escape game using the HP Reveal App to overlay specific images and objects [43]. When students scanned game items, they discovered videos, links, and other interactive elements. At the beginning a roadmap was given out, containing the game introductions, hint approach, puzzle path, and instructions. The goal is to stop a virus called WannaCry by unlocking the physical breakout box. For this, each color-coded group (blue, yellow, red, and green) had to solve three puzzles based on linear algebra, cryptography, or calculus. The second puzzle could only be solved if all groups worked together. An option to modify the game, so that the groups can compete against each other, is also given. Some escape games assign roles to the students in order to improve collaboration and structure the activity, e.g., resource manager, recorder/reporter, facilitator, or task manager [40,42]. This is mostly the case for primary or lower secondary escape games where self-organization within the groups may be more challenging for the learners. In most escape games that we reviewed hints are provided by the teacher in oral form upon students' request. In some cases, hints are incorporated into the game materials in the form of clue cards [43], hintbooks [40] and hints in exchange [36]. Fuentes-Cabrera, Parra-González, López-Belmonte, and Segura-Robles (2020) designed a physical escape room with timed puzzles, meaning each puzzle had to be solved within a certain time limit [36]. If the time ran out before students solved the puzzle, they received a clue or a new puzzle. For each puzzle solved within the time limit students earned a badge, which they could exchange for a hint or extra points. The escape activity covers a whole teaching unit consisting of five linear puzzles. Puzzles, props, and clues were color-coded for each group, which seemed a great way to allow multiple groups to play the escape room at the same time.

3.3. Educational Escape Rooms in Physics Education

All six publications targeted secondary education. The escape games addressed the following topics: photovoltaic effect [45], physics of fluids [46,47], anti-matter [48] and electromagnets [49]. Monnot, Laborie, Hérbrard, and Dietrich (2020) do not specify the learning objectives of the described escape games [50]. The publication features a game maker approach, so different physical escape rooms and labs were designed by the students in groups of 5 to 10. Each of their escape rooms consisted of at least one locked box containing the exit key, included lab-based activities and targeted general chemistry and physics knowledge. Clues, videos, and detailed instructions were provided through a tablet. Two publications featured digital escape games. Hou and Chous (2012) developed a digital escape chamber where the students had to assemble an electromagnet and use it to get the key [49]. Fotovolt is a 2D point-and-click escape game for upper secondary education designed by Tulha, de Carvalho, and Coluci (2019) [45]. The game is based on constructionism theory and is integrated into a remote physics lab. A narrative or game goal is not mentioned, but there are six game phases dealing with the properties of light, electric energy, conductive materials, energy conversion, tension, and angulation. Two physical escape rooms addressed the physics of fluids, but contained different subtopics, like speed of efflux [47] or Pascal's law [46]. They both consisted of five linear puzzles and used envelopes as locks. Some physical escape games with hands-on or lab-based activities required advanced equipment, such as 3D pointers, x-ray machines or semiconductors [48], which makes them difficult for use in other educational settings. All mentioned physics escape games included lab-based activities.

3.4. Educational Escape Rooms in Biology Education

The biology escape games (3) were mainly designed for secondary education. Primary education was not targeted in our sample. Only Brady and Andersen (2019) developed a physical escape room for university students to review the course concepts of genetics analysis before the final exam [50,51]. In line with the learning objective, the theme firefly genetics was chosen. The proposed game cannot be played by multiple groups at the same time, due to the excessive use of physical space and props. In comparison to other escape rooms, the teacher had a more active role, verifying answers, giving instructions at specific stages of the game, guiding struggling groups, and handing out props, keys, and posters as puzzle rewards. The authors see the game master role of the teacher as a great way to observe students' problem solving and assess their aptitudes. Escaping from one or more rooms was the most popular goal for escape rooms in general. This was not the case for the biology escape games. The game goal in the biology domain was either to discover a secret [52], solve a crime [53], or to prove your worth and receive the Nobel Prize [51]. Bartlett and Anderson designed a tabletop escape game about decomposers and the process of decomposition. The narrative is set in a dystopian world where nearly all viable topsoil is lost. The only hope for mankind is to discover the secret research results of the shutdown lab. To solve the six puzzles students sorted pictures of "trash" (e.g., broken glass, a soda can, a tea bag), played a card game simulating the decomposition of different objects or calculating the C:N ratio. Customizable password-protected QR-codes were generated as digital locks using QuickMark. This reduced the need for padlocked boxes and enabled the development of an entirely print-and-play version of the game. Healy (2019) also designed a tabletop escape game about entomology, including lab-based activities and live insects [53]. Students learn how insects can cause death and disease in humans and animals by solving a murder mystery and saving the falsely convicted John. Instruction cards and a set number of hint tokens are used, so that the teacher does not need to act as the game master. "The room of keys", developed by Mystakidis, Cachafeiro, and Hatzilygeroudis (2020), is an award-winning digital escape room about the structure and function of enzymes [54]. Prior to solving puzzles, students walk through a tutorial and expositional phase. The overall game play takes about 15 min. In addition to the tutorial phase the game includes simulated lab-based activities. The game provides audio and visual information to cover different learner types.

3.5. Educational Escape Rooms in Computer Science Education

More than half (7) of the 13 publications in the field of computer science targeted higher education, followed by secondary (4) and primary education (2). All of the publications aimed at promoting computational thinking (CK) as well as computer science problem solving [55]. Some common features of computational thinking include the logical organization and analysis of data, automated problem solving, and high efficiency as well as transferability of results [56]. In the scenario by Kahila, et al. (2020), for primary education, physical and virtual elements were combined [57]. The story of the game is that the children are sent to the Earth's orbit in a spaceship due to the fact that humankind has failed to stop climate change rendering the living conditions on Earth unhabitable. Now that the conditions have been restored, the children must solve some technical problems with the spaceship and plan how to land it safely. Many of the puzzles—mostly minigames—were hidden behind QR-codes distributed in the room. Due to the young target group, the games provided first insights into computational thinking—understanding of binary logic, basic ideas of program execution, decrypting codes, and so on. For instance, in one of the games the players had to find the most energy efficient route from the generator to the engines. In an escape room for 10th graders by Hacke (2019) students were sent on a spy mission [55]. They needed to identify the tasks of the next computer science exam stored on a tablet protected by a password and an alarm system in the room. The students had to solve three puzzles, for instance decrypting an encoded message, to unlock the tablet. One of the hints involved a digital camera which (after the memory card for it has been found) contained photos of objects in the room leading to further clues. López-Pernas et al., (2019) describe an educational escape room for higher education in a programming course (HTML, CSS, JavaScript etc.) for Bachelor students [58]. This game aimed at improving the students' knowledge of programming concepts. The story was built upon the challenge to decipher the genetic code of a vaccine against a deadly virus. The data leading to this code was contained in an unfinished application which was developed using the computer languages from the course. The students then had to rebuild the application and gain access to the code. While the games for primary and secondary education mainly focus on general computational thinking, this is an example of how scenarios for higher education include the content of the respective course.

3.6. Educational Escape Rooms in General Science and Enviromental Science

A total of five papers from the field of general science (STEM education) were identified in our review, three of them for secondary education. Veldkamp et al., (2020) designed an escape box for 15–16-year-old students containing analog and digital puzzles on different topics and socio-scientific issues such as climate change, plastic soup or infectious diseases [59]. The only proposal for primary education was published by Lin, Wang, Zhung and Wang (2017) [60]. They designed a fully digital escape room on the science behind papermaking. One scenario for higher education [61] focused on pre-service teachers as well as general concepts of astronomy (planets, satellites, etc.), mathematics (radius, perimeter), and science (density), under the overarching theme of sustainability. In an online setting, the pre-service teachers had to use their knowledge on these topics to complete a challenge given to them by the scientist Carl Sagan.

The two proposals from the field of environmental science both focus on higher education. Pater (2020) developed a game called "Unlock the Future" with the goal to increase the environmental attitudes and efficacy beliefs of the players [62]. The players need to "travel back in time" to stop climate change and save the earth. Chang (2019) followed a similar approach (dystopian future) but focused more on issues surrounding waste disposal [63].

3.7. Educational Escape Rooms in Medicine

As mentioned above, we were surprised by the numerous publications from the field of medicine (see Table 1). At this point, we would like to give a brief insight into the escape rooms in this domain. Many of the proposals (16) focus on the education of nurses. These games mainly focus on consolidating basic, routine procedures and concepts which frequently appear in a typical nursing working environment, for instance, the interpretation of laboratory results [64], improvement of patient care [65], or basic skills in clinical practice such as handling protective equipment or maintaining hand hygiene [66]. In a scenario called "operation outbreak", Frederick and Reed (2021) built upon the non-satisfactory results of a nursing exam and included content areas where scores had been the lowest (environmental cleaning, Spaulding classification, phases of anesthesia, surgical hand scrub, wound classification, patient safety, wound closure) [67]. In one of the eight puzzles, for example, the nurses had to put the steps of a surgical hand scrub in the correct order. After the intervention, an improvement in exam scores was observed.

Other escape rooms targeted medical, dentistry, and pharmacy students or healthcare professionals, also targeted at routine skills. In later professional life, these skills are often required to be carried out in certain stressful situations and under time pressures, just as in the game. From our point of view, this is one of the main reasons for the popularity of escape game format in the medical realm. Wilby and Kremer (2020) designed a short (five puzzles/quiz-based activities) escape room on basic knowledge of cancer and cancer treatment for medical students [68]. In one of them, the players had to find symptoms of non-Hodgkin's lymphoma in the room, distinguish them from other symptoms, and put them in a specific order to obtain a code. In a game by Sanders, Kutzin, and Strother (2021), the players (healthcare workers) were locked in the simulation room by a serial killer and needed to escape by applying their knowledge of anion gap metabolic acidosis, pneumothorax, chest tube insertion, use of an ultrasound machine, as well as Brose low tape for pediatric resuscitations [69]. Among other activities, the players had to arrange a series of radiographs in the correct order or make a laryngoscope work by finding missing batteries.

3.8. Empirical Research on the Effects of EER

Most of the reviewed publications describe specific game scenarios with little, if any, evidence on their effectiveness. For example, Clapson et al., (2020) use a simple evaluation questionnaire with questions such as "If you could repeat this activity, what would you do differently?" for the test subjects' initial assessment of the game [31]. López-Pernas et al., (2019) argue that previous works on educational escape rooms have "failed to assess the impact of this sort of activities in terms of learning effectiveness" (p. 184221). However, learning effectiveness is not the only thing that may theoretically be measured using statistical tests or assessed using qualitative methods—aspects such as motivation, interest, student activation, and others may also be evaluated.

López-Pernas et al., (2019) used a pre-post-test research design to assess the learning effectiveness of their scenario [58]. The score difference was not only statistically significant but showed (especially for educational studies) a sizeable Cohen's d effect size (0.73). Chang (2019) implemented a control and treatment group design in a quite large undergraduate course (*n* = 452) to test the effectiveness of her environmental science escape room [63]. She conducted focus group interviews after the game and used a pre- and post-questionnaire on environmental values, behaviors, and sense of agency, concluding that no significant differences between the two groups had been found when it came to changes in values, but significant differences were present as regards behavior changes. Only Chang (2019), as mentioned above, and Fuentes-Cabrera et al., (2020) used a control and treatment group design. The latter conducted an ad hoc questionnaire consisting of 32 items to research gender differences and a possible correlation between the dimensions achievement, anxiety, motivation, and autonomy. The authors found a statistically significant improvement of all four research dimensions in both groups, with the treatment group achieving higher results than the control group. Neither gender differences nor any kind of correlation could be found in the control group, whereas women had the highest level of anxiety and were the most motivated in the treatment group. At the moment there is no clear empirical evidence on the learning effect of escape games in comparison to a more traditional, lecture-based learning approach using a control and treatment group design. Some studies use previously established instruments to evaluate their games. Pater (2020) used the well-established GUESS scale [70] with nine subscales, including enjoyment, social connectivity, and visual aesthetics. Lin et al., (2017) used Kiili's flow scale (2006) [71] to measure the learners' state of flow, which turned out to be high. Yllana-Pietro, Jeong, and González-Gómez (2021) implemented a pre-post questionnaire measuring attitude, self-efficacy, and emotions towards science by running several statistical tests [61]. They observed an increase in positive attitude and high self-efficacy items, as well as the emotions "joy", "satisfaction" and "fun", but also negative emotions such as "nervousness" due to the unfamiliar online setting. There are quite a few studies using pre-post surveys or tests to measure the potential learning effect or affective outcomes, such as motivation, interest, and engagement, e.g., [43,51,54,60–63]. In particular, Berthod, Bouchoud, Grossrieder, Falaschi, Senhaji, and Bonnabry (2020) and Eukels' publications are to be mentioned. Berthod et al., (2020) found a significant increase in correct answers after the escape game activity. One month later, the same post-test was conducted again. Even then, 80% of the given answers were correct compared to 50% of correct answers in the pretest [72]. Eukel and his fellow researchers have developed multiple escape games for medical disciplines and researched their impact on students' content knowledge [73,74]. For example, Caldas, Eukel, Matulewicz, Fernández, and Donohoe (2019) conducted a pre- and post-assessment test. The post-test included the content-related questions of the pretest and an additional perception questionnaire. The assessment score improved significantly from 50% to 83.3%. To research whether escape games have a long-lasting learning effect, multiple post-tests need to be undertaken at different time intervals. It should be mentioned that none of the analyzed publications have researched which game components exactly influence students learning in a positive way. Therefore, thus far it cannot be postulated why the use of educational escape games benefits learning.

Some researchers rely on qualitative data to analyze students' interactions or to gain information that can potentially help to improve the game design. In a design-based research approach [75], Veldkamp et al., (2020) used classroom observations to evaluate the state of immersion of the students and formulate design principles for educational escape rooms [59]. Hacke (2019) conducted a video analysis of the students while playing (with over 200 participants) and analyzed the videos to identify participants' success in problem solving. In advance, he operationalized specific behaviors (e.g., systematic search for clues) that allowed for conclusions on the problem solving strategies [55].

4. Discussion and Conclusions: Identifying (Research) Gaps

As outlined above, playing and learning are closely connected, therefore, gamification in general as well as educational escape rooms in particular can be considered a "hot topic" in the STEM education community. Our literature review has shown that numerous proposals for the implementation of educational escape rooms in the field of STEM have been published, especially in the last five years. Nevertheless, we were able to identify some gaps in the research and development on this topic. First of all, there is still a need for new proposals mainly in the subjects of physics and biology. Additionally, interdisciplinary scenarios covering several domains, as well as games from the field of environmental science, are still missing. Generally, there is a lack of interdisciplinary approaches. A positive finding is that most of the chemistry, physics, and biology settings use experiments to make the learning experience more varied and promote specific experimental skills which are highly relevant in these subjects. On the other hand, educators could consider creating games that are more simple, easily adaptable, less time-consuming games, and without the use of experiments. Our impression was that the escape rooms published so far were mainly adapted to the needs of a specific course or institution—this is understandable but limits the transferability of such proposals to other institutions and learning groups. The STEM education community would certainly benefit from a more systematic approach when it comes to covering standard school or higher education topics which are taught all around the world. As regards the levels of education for which the proposals are designed, most of them targeted tertiary education, so there is a great potential for development especially in the field of secondary education (and also primary education). Such a systematization can be achieved by several steps. First, we suggest implementing a database where all educational escape rooms available are collected and can be easily browsed—our review could be a starting point for this. Second, there is a need for a set of design principles for educational escape rooms. Veldkamp et al., 2020 outlined a first proposal on this issue which can serve as a basis for further discussions. Finally, there is a general need for more empirical evidence. Many of the publications we found were small-scale studies that used observations or feedback questionnaires. From our point of view, the following aspects can be of research interest: studies on how educational escape games affect motivation, collaboration, creativity, and problem solving; research on games that are set up to identify students' misconceptions or to confront them; as well as research on the effects of educational escape rooms for knowledge acquisition. Here, the potential research questions highly depend on the goals of the respective escape rooms. We realize that the goals differ depending on the domain. They vary from the promotion of content knowledge and scientific thinking (e.g., in chemistry, biology, or physics) to computational thinking (computer science) or the consolidation of routine procedures (medicine). Some of the available escape games are designed to be played remotely. It would be interesting to inquire as to whether such scenarios have comparable effects to live, physical escape rooms. When it comes to the technical implementation of the scenarios, we can say that while some of the games used digital settings, most of them can be considered to be quite low-tech. The potential future inclusion of virtual reality or augmented reality technologies will lead to new research interests on immersive learning environments with almost no spatial limitations.

In summary, educational escape rooms seem to be an engaging way to "gamify" STEM learning, however a much more systematic approach as well as more evidence is needed. Thus, educational escape rooms are not a declining trend yet, but scholars need to fill these existing gaps and create broadly adaptable frameworks in order to make full use of the potential of such teaching and learning scenarios.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/educsci11060308/s1. Here we can provide a table showing all the analyzed results together with a short description of each escape room.

Author Contributions: Conceptualization, C.L. and N.B.; methodology, C.L. and N.B.; investigation, C.L. and N.B.; writing—original draft preparation, C.L. and N.B.; writing—review and editing, C.L. and N.B. 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.

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

References

1. Roberts, J.M.; Arth, M.J.; Bush, R.R. Games in Culture. *Am. Anthr.* **1959**, *61*, 597–605. [CrossRef]
2. Murray, J. The play's the thing. *Int. J. Early Years Educ.* **2017**, *26*, 335–339. [CrossRef]
3. Vygotsky, L.S. *Mind in Society: The Development of Higher Psychological Processes*; Harvard University Press: Cambridge, MA, USA, 1980.
4. Kim, S.; Song, K.; Lockee, B.; Burton, J. What is Gamification in Learning and Education? In *Gamification in Learning and Education*; Springer Science and Business Media LLC: Berlin/Heidelberg, Germany, 2018; pp. 25–38.
5. Martinez-Garza, M.; Clark, D.B.; Nelson, B.C. Digital games and the US National Research Council's science proficiency goals. *Stud. Sci. Educ.* **2013**, *49*, 170–208. [CrossRef]
6. Young, M.F.; Slota, S.; Cutter, A.B.; Jalette, G.; Mullin, G.; Lai, B.; Simeoni, Z.; Tran, M.; Yukhymenko, M. Our Princess Is in Another Castle. *Rev. Educ. Res.* **2012**, *82*, 61–89. [CrossRef]
7. Tsekleves, E.; Cosmas, J.; Aggoun, A. Benefits, barriers and guideline recommendations for the implementation of serious games in education for stakeholders and policymakers. *Br. J. Educ. Technol.* **2014**, *47*, 164–183. [CrossRef]
8. Raitskaya, L.; Tikhonova, E. Gamification as a Field Landmark in Educational Research. *J. Lang. Educ.* **2019**, *5*, 4–10. [CrossRef]
9. Gros, B. Digital Games in Education. *J. Res. Technol. Educ.* **2007**, *40*, 23–38. [CrossRef]
10. Deterding, S.; Dixon, D.; Khaled, R.; Nacke, L. From game design elements to gamefulness. In Proceedings of the 15th International Academic MindTrek Conference on Envisioning Future Media Environments-MindTrek '11, Tampere, Finland, 28–30 September 2011; Association for Computing Machinery (ACM): New York, NY, USA, 2011; pp. 9–15.
11. Aynsley, S.; Nathawat, K.; Crawford, R.M. Evaluating student perceptions of using a game-based approach to aid learning: Braincept. *High. Educ. Pedagog.* **2018**, *3*, 478–489. [CrossRef]
12. Mora, A.; Riera, D.; González-González, C.S.; Arnedo-Moreno, J. Gamification: A systematic review of design frameworks. *J. Comput. High. Educ.* **2017**, *29*, 516–548. [CrossRef]
13. Csikszentmihalyi, M. *Flow: The Psychology of Optimal Experience*; Harper & Row: New York, NY, USA, 1990.
14. Nicholson, S. Peeking behind the Locked Door: A Survey of Escape Room Facilities, 2015, White Paper. Available online: http://scottnicholson.com/pubs/erfacwhite.pdf (accessed on 18 May 2021).
15. Nicholson, S. Ask Why. Creating a Better Player Experience through Environmental Storytelling and Consistency in Escape Room Design. Paper Presented at Meaningful Play, East Lansing, Michigan, USA, October 2016. Available online: http://scottnicholson.com/pubs/askwhy.pdf (accessed on 18 May 2021).
16. Wiemker, M.; Elumir, E.; Clare, A. Escape Room Games. In *Game Based Learning-Dialogorientierung und Spielerisches Lernen Digital und Analog*; Haag, J., Weißenböck, J., Gruber, W., Freisleben-Teutscher, C.F., Eds.; Fachhochschule St. Pölten GmbH: St. Pölten, Austria, 2015; pp. 55–68.
17. Fotaris, P.; Mastoras, T. Escape Rooms for Learning: A Systematic Review. In Proceedings of the 13th International Conference on Game Based Learning, ECGBL, Odense, Denmark, 3–4 October 2019; Elbaek, L., Majgaard, G., Valente, A., Khalid, S., Eds.; Academic Conferences and Publishing International Limited: Reading, UK, 2019; pp. 235–243.
18. LookingatLearning. EDUESC@PEROOM: Manual Report for Educators. Available online: https://drive.google.com/file/d/0B23HzLyhtRAMUGtYQmJtMWM1UVk/view (accessed on 26 April 2021).
19. LookingatLearning. EDUESC@PEROOM: Tutorial. Available online: https://drive.google.com/file/d/0B23HzLyhtRAMbGJzLVk0aHlGeFk/view (accessed on 26 April 2021).
20. School Break. Using Escape Rooms in Teaching. Available online: http://www.school-break.eu/wp-content/uploads/2020/03/SB_Handbook_1_eER_use_in_teaching.pdf (accessed on 26 April 2021).
21. Sundsbø, K. Open Access Escape Room: The key to OA engagement? *Insights UKSG J.* **2019**, *32*, 1–7. [CrossRef]
22. Nephew, S.; Sunasee, R. An Engaging and Fun Breakout Activity for Educators and Students about Laboratory Safety. *J. Chem. Educ.* **2021**, *98*, 186–190. [CrossRef]
23. Gilbert, B.C.T.; Clapson, M.L.; Musgrove, A. ChemEscape, Polymer Chemistry: Solving Interactive Puzzles Featuring Scaffolded Learning to Promote Student Understanding of Polymers and Structure–Property Relationships. *J. Chem. Educ.* **2020**, *97*, 4055–4062. [CrossRef]
24. Yayon, M.; Rap, S.; Adler, V.; Haimovich, I.; Levy, H.; Blonder, R. Do-It-Yourself: Creating and Implementing a Periodic Table of the Elements Chemical Escape Room. *J. Chem. Educ.* **2019**, *97*, 132–136. [CrossRef]
25. Dietrich, N. Escape Classroom: The Leblanc Process—An Educational "Escape Game". *J. Chem. Educ.* **2018**, *95*, 996–999. [CrossRef]
26. Peleg, R.; Yayon, M.; Katchevich, D.; Moria-Shipony, M.; Blonder, R. A Lab-Based Chemical Escape Room: Educational, Mobile, and Fun! *J. Chem. Educ.* **2019**, *96*, 955–960. [CrossRef]
27. Strippel, C.G.; Schröder, T.; Sommer, K. Ein Lehr-Lern-Mittel für elektrochemische Experimente im Eigenbau: Experimentelle Escape Box. *Chem. Unserer Zeit* **2021**, *55*, 1–7. [CrossRef]
28. Estudante, A.; Dietrich, N. Using Augmented Reality to Stimulate Students and Diffuse Escape Game Activities to Larger Audiences. *J. Chem. Educ.* **2020**, *97*, 1368–1374. [CrossRef]

29. Ferreiro-González, M.; Amores-Arrocha, A.; Espada-Bellido, E.; González, M.J.A.; Vázquez-Espinosa, M.; González-De-Peredo, A.V.; Sancho-Galán, P.; Álvarez-Saura, J.Á.; Barbero, G.F.; Cejudo-Bastante, C. Escape ClassRoom: Can You Solve a Crime Using the Analytical Process? *J. Chem. Educ.* **2019**, *96*, 267–273. [CrossRef]
30. Groß, K.; Schumacher, A. Chemistry Escape–Finde den Weg. *Chem. Unserer Zeit* **2020**, *54*, 126–130. [CrossRef]
31. Clapson, M.L.; Gilbert, B.; Mozol, V.J.; Schechtel, S.; Tran, J.; White, S. ChemEscape: Educational Battle Box Puzzle Activities for Engaging Outreach and Active Learning in General Chemistry. *J. Chem. Educ.* **2019**, *97*, 125–131. [CrossRef]
32. Moura, A.; Santos, I.L. Escape Room in Education: Gamifying learning to engage students and learn Maths and Languages. In *Experiences and Perceptions of Pedagogical Practices with Game-Based Learning and Gamification*; Silva, B.D.d., Lencastre, J.A., Bento, M., Osório, A.J., Eds.; CIEd: Braga, Portugal, 2019; pp. 179–194.
33. Arnal-Palacián, M.; Macías-García, J.A.; Duarte Tosso, I. Escape Rooms as a Way to Teach Magnitudes and Measure in Degrees in Education. In Proceedings of the 8th International Conference New Perspectives in Science Education, Florence, Italy, 21–22 March 2019; Pixel, Ed.; Filodiritto: Bologna, Italy, 2019; pp. 79–84.
34. Educational Escape Room for Approaching the Concept of Length on Blind Students. In Proceedings of the 12th European Conference on Game Based Learning, Sophia Antipolis, France, 4–5 October 2018; Academic Conferences International Ltd.: Reading, UK, 2019; pp. 832–838.
35. Glavaš, A.; Staščik, A. Enhancing positive attitude towards mathematics through introducing Escape Room games. In *Mathematics Education as a Science and a Profession*; Kolar-Begović, Z., Kolar-Šuper, R., Jukić Matić, L., Eds.; ELEMENT: Osijek, Croatia, 2017; pp. 281–294.
36. Fuentes-Cabrera, A.; Parra-González, M.E.; López-Belmonte, J.; Segura-Robles, A. Learning Mathematics with Emerging Methodologies—The Escape Room as a Case Study. *Mathematics* **2020**, *8*, 1586. [CrossRef]
37. Stohlmann, M.S. Escape Room Math: Luna's Lines. *Math. Teach.* **2020**, *113*, 383–389. [CrossRef]
38. Jiménez, C.; Arís, N.; Ruiz Ángel, A.M.; Orcos, L. Digital Escape Room, Using Genial.Ly and A Breakout to Learn Algebra at Secondary Education Level in Spain. *Educ. Sci.* **2020**, *10*, 271. [CrossRef]
39. Sánchez-Martín, J.; Corrales-Serrano, M.; Luque, A.; Zamora-Polo, F. Exit for success. Gamifying science and technology for university students using escape-room. A preliminary approach. *Heliyon* **2020**, *6*, e04340. [CrossRef]
40. Charlo, J.C.P. Educational Escape Rooms as a Tool for Horizontal Mathematization: Learning Process Evidence. *Educ. Sci.* **2020**, *10*, 213. [CrossRef]
41. Otemaier, K.R.; Zanese, P.G.; Grein, E.E.; Bosso, N.S. Educational escape room for teaching Mathematical Logic in computer courses. In SBC—Proceedings of the SBGames, Recife, Brazil, 7–10 November 2020; Sociedade Brasileira de Computação: Porto Alegre, Brazil, 2020; pp. 595–604.
42. Elsner, E. *How Discourse and Collaboration Can be Used in Mathematics Classrooms to Promote Engagement and Learning Master of Arts in Education*; Hamline University: Saint Paul, MN, USA, 2019.
43. Queiruga-Dios, A.; Sánchez, M.J.S.; Dios, M.Q.; Martínez, V.G.; Encinas, A.H. A Virus Infected Your Laptop. Let's Play an Escape Game. *Mathematics* **2020**, *8*, 166. [CrossRef]
44. Kirova, G. "The Room of Mysteries" Project for the third Grade. *Knowl. Int. J.* **2019**, *76*, 134–139.
45. Tulha, C.N.; De Carvalho, M.A.G.; Coluci, V.R. Educational Digital Game Integrated into a Remote Laboratory for Learning Physic Concepts. In Proceedings of the 2019 IEEE 19th International Conference on Advanced Learning Technologies (ICALT), Maceio, Brazil, 15–18 July 2019; pp. 234–235.
46. Vita Vörös, A.I. Educational Escape Rooms for Physics of Fluids. In Proceedings of the Programme and Book of Abstracts of the GIREP-ICPEEPEC-MPTL Conference 2019, Budapest, Hungary, 1–5 July 2019.
47. Vörös, A.I.V.; Sárközi, Z. Physics escape room as an educational tool. In Proceedings of the Tim17 Physics Conference, Timisoara, Romania, 25–27 May 2017; pp. 050002-1–050002-6. [CrossRef]
48. Woithe, J. Escape Games in Physics Education: Students' Attitudes and Flow Experience. In Proceedings of the GIREP-ICPE-EPEC-MPTL 2019 Conference, Budapest, Hungary, 1–5 July 2019.
49. Hou, H.-T.; Chou, Y.-S. Exploring the technology acceptance and flow state of a chamber escape game–Escape the lab© for learning electromagnet concept. In Proceedings of the 20th International Conference on Computers in Education (ICCE), Singapore, 26–30 November 2012; pp. 38–41.
50. Monnot, M.; Laborie, S.; Hébrard, G.; Dietrich, N. New approaches to adapt escape game activities to large audience in chemical engineering: Numeric supports and students' participation. *Educ. Chem. Eng.* **2020**, *32*, 50–58. [CrossRef]
51. Brady, S.C.; Andersen, E.C. An escape-room inspired game for genetics review. *J. Biol. Educ.* **2019**, *X*, 1–12. [CrossRef]
52. Bartlett, K.A.; Anderson, J.L. Gaming to Learn. In *Handbook of Research on Applying Universal Design for Learning Across Disciplines*; IGI Global: Derry Township, PA, USA, 2019; pp. 1–27.
53. Healy, K. Using an Escape-Room-Themed Curriculum to Engage and Educate Generation Z Students About Entomology. *Am. Entomol.* **2019**, *65*, 24–28. [CrossRef]
54. Mystakidis, S.; Cachafeiro, E.; Hatzilygeroudis, I. Enter the Serious E-scape Room: A Cost-Effective Serious Game Model for Deep and Meaningful E-learning. In Proceedings of the 2019 10th International Conference on Information, Intelligence, Systems and Applications (IISA), Patras, Greece, 15–17 July 2019; pp. 1–6.
55. Hacke, A. Computer Science Problem Solving in the Escape Game Room-X. In *Transactions on Petri Nets and Other Models of Concurrency XV*; Springer Science and Business Media LLC: Berlin/Heidelberg, Germany, 2019; pp. 281–292.

56. International Society for Technology in Education (ISTE). Operational Definition of Computational Thinking for K-12 Education. 2011. Available online: http://www.iste.org/docs/pdfs/Operational-Definition-of-Computational-Thinking.pdf (accessed on 11 May 2021).
57. Kahila, J.; Parkki, T.; Gröhn, A.; Karvinen, A.; Telimaa, E.; Riikonen, P.; Tiitta, R.; Haantio, P.; Keinänen, A.; Kerkkänen, T.; et al. Escape Room Game for CT Learning Activities in the Primary School. In Koli Calling '20 Proceedings of the 20th Koli Calling International Conference on Computing Education Research, Koli, Finland, 19–22 November 2020; ACM: New York, NY, USA, 2020; pp. 1–5.
58. Lopez-Pernas, S.; Gordillo, A.; Barra, E.; Quemada, J. Analyzing Learning Effectiveness and Students' Perceptions of an Educational Escape Room in a Programming Course in Higher Education. *IEEE Access* **2019**, *7*, 184221–184234. [CrossRef]
59. Veldkamp, A.; Daemen, J.; Teekens, S.; Koelewijn, S.; Knippels, M.P.J.; Van Joolingen, W.R. Escape boxes: Bringing escape room experience into the classroom. *Br. J. Educ. Technol.* **2020**, *51*, 1220–1239. [CrossRef]
60. Lin, F.-J.; Wang, C.-P.; Zhung, H.-C.; Wang, H.-Y.; Wang, S.-M.; Li, C.-T.; Li, M.-C.; Hou, H.-T. Paper Romance©—An Educational Simulation Game for Learning Papermaking with Contextual Scaffoldings for Elementary Students: The Evaluation of Learning Performance and Flow State. In Proceedings of the 2017 6th IIAI International Congress on Advanced Applied Informatics (IIAI-AAI), Hamamatsu, Japan, 9–13 July 2017; pp. 1007–1008. [CrossRef]
61. Yllana-Prieto, F.; Jeong, J.S.; González-Gómez, D. An Online-Based Edu-Escape Room: A Comparison Study of a Multidimensional Domain of PSTs with Flipped Sustainability-STEM Contents. *Sustainability* **2021**, *13*, 1032. [CrossRef]
62. Pater, E. "Unlock the Future": An Environmental Escape Game and its Development, Evaluation and Impact. Master's Thesis, Uppsala University, Uppsala, Sweden, 2020.
63. Chang, H.-Y.H. Escaping the Gap: Escape Rooms as an Environmental Education Tool. University of California. 2019. Available online: https://nature.berkeley.edu/classes/es196/projects/2019final/ChangH_2019.pdf (accessed on 18 May 2021).
64. Brown, N.; Darby, W.; Coronel, H. An Escape Room as a Simulation Teaching Strategy. *Clin. Simul. Nurs.* **2019**, *30*, 1–6. [CrossRef]
65. Martin, L.S.; Walsh, H.; Santerre, M.; Fortkiewicz, J.; Nicholson, L. Creation of a "Patient" Hospital Escape Room Experience to Reduce Harm and Improve Quality of Care. *J. Nurs. Care Qual.* **2021**, *36*, 38–42. [CrossRef] [PubMed]
66. McLaughlin, J.L.; Reed, J.A.; Shiveley, J.; Lee, S. Escape Room Blueprint: Central Orientation Contagion Crisis. *Simul. Gaming* **2021**, *52*, 24–30. [CrossRef]
67. Frederick, A.N.; Reed, J.A. Operation Outbreak: A Periop 101 Exam Review Escape Room. *Simul. Gaming* **2021**, *52*, 88–95. [CrossRef]
68. Wilby, K.J.; Kremer, L.J. Development of a cancer-themed escape room learning activity for undergraduate pharmacy students. *Int. J. Pharm. Pract.* **2020**, *28*, 541–543. [CrossRef]
69. Sanders, J.E.; Kutzin, J.; Strother, C.G. Escape the Simulation Room. *Simul. Gaming* **2021**, *52*, 62–71. [CrossRef]
70. Phan, M.H.; Keebler, J.; Chaparro, B.S. The Development and Validation of the Game User Experience Satisfaction Scale (GUESS). *Hum. Factors J. Hum. Factors Ergon. Soc.* **2016**, *58*, 1217–1247. [CrossRef]
71. Kiili, K. Evaluations of an Experiential Gaming Model. *Hum. Technol.* **2006**, *2*, 187–201. [CrossRef]
72. Berthod, F.; Bouchoud, L.; Grossrieder, F.; Falaschi, L.; Senhaji, S.; Bonnabry, P. Learning good manufacturing practices in an escape room: Validation of a new pedagogical tool. *J. Oncol. Pharm. Pract.* **2019**, *26*, 853–860. [CrossRef]
73. Morrell, B.; Eukel, H.N. Shocking Escape: A Cardiac Escape Room for Undergraduate Nursing Students. *Simul. Gaming* **2021**, *52*, 72–78. [CrossRef]
74. Caldas, L.M.; Eukel, H.N.; Matulewicz, A.T.; Fernández, E.V.; Donohoe, K.L. Applying educational gaming success to a nonsterile compounding escape room. *Curr. Pharm. Teach. Learn.* **2019**, *11*, 1049–1054. [CrossRef]
75. Bakker, A. *Design Research in Education: A Practical Guide for Early Career Researchers*; Routledge: New York, NY, USA, 2018.

education sciences

Article

Assessment of *Scratch* Programming Language as a Didactic Tool to Teach Functions

Eduardo Quevedo Gutiérrez [1,*] and Alberto Zapatera Llinares [2]

1 Institute for Applied Microelectronics, Campus de Tafira, University of Las Palmas de Gran Canaria, 35017 Las Palmas de Gran Canaria, Spain
2 Department of Educational Sciences, University CEU Cardenal Herrera, C/Carmelitas 1, 03203 Elche, Spain; alberto.zapatera@uchceu.es
* Correspondence: equevedo@iuma.ulpgc.es

Abstract: The objective of this research is to study the *Scratch* programming language as a didactic tool to teach functions. The introduction of didactic tools allowing comprehension in simple and attractive ways is required. Given the traditional teaching/learning system, it is necessary to organize participatory and collaborative dynamic classrooms, which allow the interaction of students in activities where the educator modifies his or her traditional role as an advisor and the students take a more active role in learning through their own effort. In this sense, three activities using the *Scratch* programming language are proposed: the first one refers to the linear and affine functions, while the second one deals with the quadratic function and the third one is related to the exponential function. The participants in this study were 30 future teachers. The study considers the combination of magisterial lessons and active didactic methodologies as demonstration method, cooperative learning and gamification, also including the applied assessment. The activities, methodologies and assessment were evaluated by the participants with results higher than 4 in 5-point Likert scale for all cases, preferring the active methodologies than magisterial lessons.

Keywords: assessment; computational thinking; functions; future teachers; *Scratch*

Citation: Quevedo Gutiérrez, E.; Zapatera Llinares, A. Assessment of *Scratch* Programming Language as a Didactic Tool to Teach Functions. *Educ. Sci.* **2021**, *11*, 499. https://doi.org/10.3390/educsci11090499

Academic Editors: José Carlos Piñero Charlo, María Teresa Costado Dios, Enrique Carmona Medeiro and Fernando Lloret

Received: 28 July 2021
Accepted: 31 August 2021
Published: 3 September 2021

1. Introduction

The recent study of 2016 conducted by the European Commission "Developing Computational Thinking in Compulsory Education, Implications for Policy and Practice" argues that in the past decade, computational thinking and its related concepts (for example, coding, programming or algorithmic thinking) are receiving increased attention in the educational field [1]. As a result, a lot of public and private implementation initiatives have arisen. Despite this widespread interest, the successful integration of computational thinking in compulsory education still faces unresolved issues and challenges [2]. Computational thinking as such was enunciated at the beginning of this decade. Jeannette Wing, Ph.D. in Computer Engineering from Massachusetts Institute of Technology (MIT), who is one of its greatest exponents, presented a definition focused on the use of computer concepts to carry out activities, from solving problems to understanding human behavior, going through systems' design [3]. Computational thinking is based fundamentally on two learning theories: the constructivism of Jean Piaget, a Swiss psychologist and pedagogue who defended the endowment of tools for the student to solve problems [4], and the constructionism of Seymour Papert, a mathematician, computer scientist and American educator born in South Africa, who proposed the construction of mental models to understand the world around us [5]. Both learning theories focus on the construction of elements, following the maker philosophy to solve problems.

1.1. Scratch as a Computational Thinking Didactic Tool

Scratch is a visual programming language developed by a team from MIT Media Lab, led by Mitch Resnick. *Scratch* is used by students, teachers and parents to create simple animations and interactions, fostering computational thinking, thus putting into practice the theses of Piaget and Papert [6]. The main contribution of *Scratch* is that it is intended for early age users, which makes it directly applicable as a didactic tool devoted to teaching programming to elementary students. Increasingly, students are interested in programming as a creator of different utilities, applications and games. This interest appears more and more at early ages. *Scratch* offers a perspective advanced in knowledge but simple in management [7]. As a matter of fact, *Scratch* is used in education for a wide variety of applications, such as mathematics competences [8], interdisciplinary works [9], videogames [10], logical thinking [11] or robotics [12].

There are several studies that use *Scratch* as a tool to work in mathematical-based problems. In [13], Rodríguez Martínez et al. considered the use of *Scratch* in problems focusing on the divisibility concepts of the greatest common divisor and the least common multiple, achieving a statistically significant improvement in the participants who solved problems using *Scratch*. In [14], Shahbari et al. engaged 18 prospective teachers in a sequence of mathematical problems that utilized *Scratch*, concluding that the role of the sequence side-by-side with the guidelines of the instructor, had an important role in supporting the developments of learner's meta-cognitive functions in mathematics problem-solving. *Scratch* has been also considered as a tool to teach geometry, using for instance a physical *Scratch*-based programmable artifact in order to design, implement and discuss geometry activities for primary school classes; results showed that it supposed a combination of mathematics learning opportunities for students and teachers [15].

In this paper, *Scratch* is used as a computational thinking didactic tool to teach functions. From the very beginning, since primary school courses, the acquisition of mathematical concepts through *Scratch* has been considered [13]. More specifically, the teaching of the Cartesian coordinate system, in accordance with the current educational curriculum, is a challenge for the teacher. The objective consists of students being able to describe positions and movements by means of coordinates, distances among points located in straight horizontal lines, parallelisms, perpendicularity, angles, turns, etc., using the geometric vocabulary [16].

This study considers the combination of magisterial lesson and active didactic methodologies, which are detailed in the following section, assessing the contents of the activities, the used methodologies and the applied assessment.

1.2. Active Didactic Methodologies and Scratch

The use of active didactic methodologies increases motivation and improves student learning autonomy in a significant way [17]. The motivation of the presented activities in this paper to show the teaching of the functions with *Scratch* is focused on proposing didactic alternatives. In this way, *Scratch* programming language is considered as a way to build the reality.

The challenge is to discern what strategies might be appropriate to be introduced in the curricula in order to achieve meaningful learning. Thus, given the traditional teaching/learning system, it is necessary to organize participatory and collaborative dynamic classrooms, which allows the interaction of students in activities where the educator modifies his or her traditional role as an advisor and the students take a more active role in learning through their own effort [18]. Therefore, a set of complementary active methodologies is sought, including the demonstration method, cooperative learning and gamification.

1.2.1. Demonstration Method

This method provides lessons by exhibiting and demonstrating. It demonstrates things, events, rules and sequences of activities, either directly or through using instructional media, which is relevant to the subject matter or material that will be presented. The purpose of teaching using the demonstration method is to show the process of occurrence of an event according to the teaching materials, how they are attained and the ease to be understood by the students in teaching learning process [19]. The demonstration method fits very well with the idea of computational thinking, since students share ideas and develop activities based on their own proposals, including new elements. Likewise, *Scratch* allows one to visualize in real time the programming of the performed task.

1.2.2. Cooperative Learning

As indicated by [20], "cooperative learning is promoted in the mid-twentieth century as a teaching strategy that favors school integration but it is proposed and supported by constructivist and sociocultural theorists as a promoter of cognitive and socio-affective development" [20]. Cooperative learning consists of the provision of small groups of students who work together in order to improve their learning. In this didactic methodology, there are three types, according to the stability or permanence of the group [21]:

1. Informal groups: Teachers can use them during a specific didactic activity, so that they can last from a few minutes to an hour or the duration of a class. The final purpose is the improvement of attention and understanding of the considered task. Thus, the group organizes, analyses, explains and interprets the information appropriately;
2. Formal groups: They are formed for a wide period of classes, for example, a trimester. Its purpose, as in the previous case, consists of participating and helping to organize, analyze and interpret the information, so that they cooperate for the achievement of individual and collective objectives;
3. Cooperative base groups: These groups are formed for long periods of time, for example, a complete course. It is intended to establish long-lasting and helpful cooperative relationships. Thus, the group serves as a support so that students do not fall behind in their learning. Therefore, its objective is to motivate the students, while offering them permanent support through peers.

Taking into account that the activities outlined in this paper to reinforce concepts related to functions would be framed in a specific quarter, perhaps it would be appropriate to raise formal groups in class, which begin to work cooperatively with *Scratch*. These groups could be extended to the complete course, becoming cooperative base groups. This makes sense if this technological tool, or others related, are used throughout the rest of the course and it is desired to have a global vision of the development of the activity carried out by the working groups. In this case, it would be appropriate to monitor the work capacity of the groups at all times, in order to make changes when necessary. A suitable number for group size would be three students, and may even be two, if the computer resources of the educational center allow it.

1.2.3. Gamification

According to [22], the term gamification can be defined as "The process of game-thinking and game mechanics to engage users and solve problems". The combination of the demonstration method and cooperative learning together with gamification manages to apply collaboratively dynamics and strategies of the game to the learning process. To accomplish this, a clear message should be defined intentionality, choosing the strategy to follow and finally evaluating and measuring progress. Games are traditionally used in early ages but stigmatized in more advanced ages, sometimes being considered a waste of time. However, in recent years, gamification has become a methodological trend with great presence in classrooms [23,24]. Consequently, a fast growth of the publications in the area of gamification in education has arisen over the past seven years. Moreover, the worldwide interest in the area is indicated by the number of countries in which the contributing authors are based and the number of institutions to which they are affiliated [25].

The approach carried out in the learning of functions through programming with *Scratch* is a game in itself. It allows the student to try different options until reaching the problem solution, without fear of making mistakes in the process. This is very interesting since the fact of not being able to reach the final solution may involve the student's motivation to continue playing and improving; on the contrary, in the education system, usually the mistakes are penalized, which can lead to demotivation [26]

1.2.4. Combination of the Proposed Methodologies

The use of cooperative learning combined with the demonstration method and gamification would provide the following advantages:

- It promotes the cognitive and socio-affective development of group members, based on a work strategy that guides to solidarity through game as an additional motivational element;
- It involves the development of teamwork skills such as communication, interaction, cooperation, commitment, responsibility or leadership;
- It reorients the individual competitive effort towards positive uses of collaboration to the achievement of individual and collective objectives.

The objective of this paper is to study the *Scratch* programming language as a didactic tool to teach functions and analyze the suitability of different methodologies to teach functions. From this perspective, the following research questions are posed:

- Is *Scratch* a suitable teaching tool for teaching functions?
- How do future teachers value the activities, methodologies and evaluation used in a teaching experience to learn functions using *Scratch*?

2. Materials and Methods

2.1. Teaching of the Cartesian Coordinate System

2.1.1. Traditional Teaching Versus Didactic Proposal

The teaching of the Cartesian coordinate system is usually oriented to didactically explain the location in a map or graphic. It is also possible to play games such as the classic "Sea Battle". Considering these possibilities, learning situations such as "El Cartesiano" have been proposed [27].

The didactic proposal which considers *Scratch* presented in this paper is focused on understanding the Cartesian coordinate system as an element integrated on the computer screen in which the student is working on. The idea is to show this proposal to future teachers who are learning mathematics didactics at the university, in order to propose an alternative to teach this topic. The *Scratch* scenario (the working window) is measured in pixels (px). The scenario dimensions are 480 px (width) by 360 px (height). Each pixel is a square which composes a digital image. Therefore, a high resolution image (1920 × 1200 px) is much bigger than the *Scratch* scenario, as shown in Figure 1.

2.1.2. The Cartesian Coordinate System in *Scratch*

Scratch allows one to select several scenarios as a template or to use new ones created by the user. There are predefined scenarios in the current version of *Scratch* (3.0), also available in the previous version (2.0), which show the Cartesian coordinate system as follows:

- *Xy-grid* scenario (Figure 2a): Cartesian coordinate system which origin is the center of the *Scratch* scenario. The limit points are presented in the axis of abscissas: (−240, 0) and (240, 0) and in the axis of ordinates: (0, 180) and (0, −180). It also includes a 100 × 100 square grid;
- *Xy-grid-30-px* scenario (Figure 2b): 30 × 30 square grid. As the dimensions of the scenario are 480 × 360 px, there are 16 squares per row and 12 squares per column;
- *Xy-grid-20-px* scenario (Figure 2c): 20 × 20 square grid. In this case, for a 480 × 360 px scenario, there are 24 squares per row and 18 squares per column.

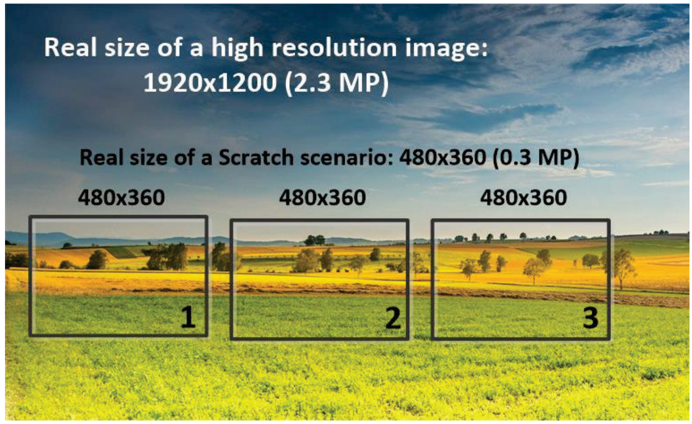
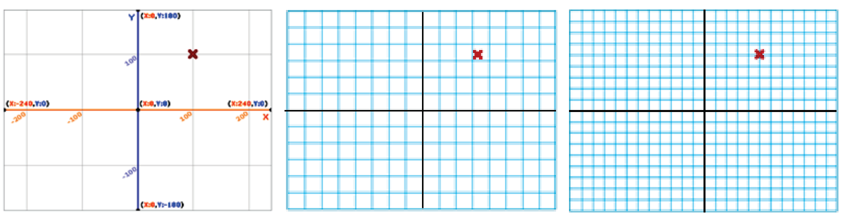


Figure 1. *Scratch* scenarios in a 1920 × 1200 px high resolution image.



(**a**) Xy-grid scenario (**b**) Xy-grid-30px scenario (**c**) Xy-grid-20px scenario

Figure 2. *Scratch* scenarios related to the Cartesian Coordinate System. As a reference a cross (object Button5) is located in coordinates (100, 100).

Scratch scenarios present a powerful didactic tool. On the one hand, the scenarios in Figure 2 are useful to work the area concept in flat figures, taking as a reference 100 × 100, 30 × 30 and 20 × 20 squares. On the other hand, to consider the position of an element in the screen, a *Scratch* object must be included. For instance, in the Figure 2 scenario, a cross (object Button5) is located at the coordinates (100, 100).

Once the Cartesian coordinate system is explained considering the *Scratch* scenarios, the didactic proposal of this paper is based on presenting and assessing three different activities based on linear, affine, quadratic and exponential functions considering the combination of the active didactic methodologies previously presented.

2.2. Proposed Activities

In this paper, three activities using the *Scratch* programming language are proposed: the first one refers to the linear and affine functions, while the second one deals with the quadratic function and the third one is related to the exponential function. The proposed activities were introduced to a group of 30 students of the Mathematics and its Didactics I subject of the Primary Education Degree of the Faculty of Education Sciences (FCEDU) of the University of Las Palmas de Gran Canaria (ULPGC). In the last didactic unit of this subject, dedicated to algebra, the linear, affine, quadratic and exponential functions are studied. The objective is to present these functions in a didactic way, so these activities were proposed as a reinforcement exercise.

2.2.1. Activity 1: Going to the Cinema with the Linear and Affine Functions

This section presents an activity applied to a linear function, which is then adapted to an affine function, based on a situation of daily life taking as a reference on a problem of multiplicative structure. This type of problems is identified with a rule of three in which there is direct proportionality. A suitable way of didactic resolution is the reduction to unity. Thus, the following problem is proposed:

"If the cost for 3 friends to go to the cinema is 18 €,
how much would it cost for 7 friends to go to the cinema?"

According to the technique which is usually explained for the direct rule of three, a cross-multiplication may be used as follows:

3 friends → 18 €
7 friends → x €
Therefore $3 \cdot x = 7 \cdot 18 \rightarrow x = 42$ €

This way of resolution is far away from the practical form of calculation which is carried out in real life, which would happen to wonder how much a ticket costs and then multiplying the cost of a ticket by the number of friends who are going to the cinema, as follows:

"If the cost for 3 friends to go to the cinema is 18 €, then the ticket costs 18/3 = 6 €
Therefore, the cost for 7 friends is 7·6 = 42 €"

This problem applied to functions could then be understood as a linear function in which the slope (m in a linear function $y = mx$) would constitute the cost of the ticket (6 €), the independent variable x would be the number of friends, and the dependent variable y would be the total cost to go to the cinema. Based on this idea, a *Scratch* program could be proposed as follows:

1. The previous example is presented considering 7 friends, so that students can see how practical the resolution by reduction to unity is.
2. Students think in the framework in which the problem is represented (the *Scratch* screen), and following questions are proposed.
    a. In which quadrants of the coordinate system can the problem solution be found? *Answer*: First quadrant (linear function). The answer changes to the first and third quadrants if an affine function is considered.
    b. What would be the maximum number of friends we can consider taking into account that the result is within the *Scratch* screen? *Answer*: 30 friends ($6 \times 30 = 180$: maximum ordinate in *Scratch* screen) for a linear function. Thus, the solution is $x = 30$ and $y = 180$. To show this result, the xy-grid-30px scenario could be used as a reference, as represented in Figure 3 (the cross marks the position for $x = 15$ and $y = 90$, just in the middle, and each square of the grid is 30×30). The answer changes depending on the ordinate of the origin if an affine function is considered.
3. A *Scratch* program is designed. In this program, the previously commented function is drawn and depending on the number of friends selected, the problem solution is marked on the function.
4. The program is modified so that the user can also enter the cost of the ticket (using a variable instead of the value "6" in Figure 3).

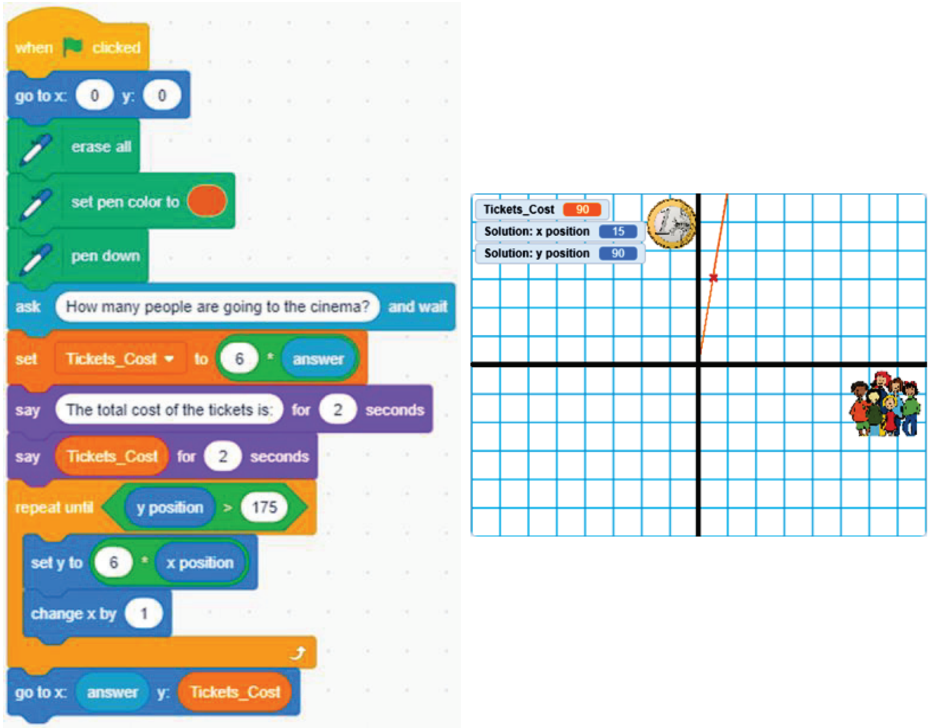


Figure 3. Linear function with the solution marked for 15 friends (cost = 90 €).

Once the linear function is studied, a variant can be considered to pass from the linear function $y = mx$ to the affine function $y = mx + n$, giving meaning to the ordinate in origin n, proposing the following alternatives:

1. On "movie day", when tickets cost 2 €, and due to high demand, in order to avoid a massive purchase of online tickets, an extra cost has been placed on the purchase (over the total) of 15 €, when the number of purchased tickets is equal to or greater than 15.
2. On "movie day", when tickets cost 2 €, a cinema in crisis has decided a discount on the purchase (over the total) of 15 € to further promote the purchase, when the number of purchased tickets is equal to or greater than 15.

The affine functions corresponding to alternatives (1) and (2) are represented in Figure 4, which appear, respectively, above and below the linear function represented.

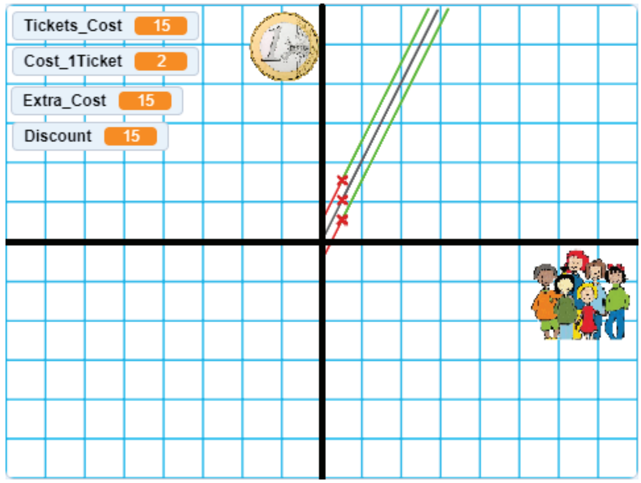


Figure 4. Affine functions representation versus linear function.

2.2.2. Activity 2: Throwing the Ball into a Basket with Quadratic Functions

Many times, students face the resolution of second degree equations according to Equation (1):

$$y = ax^2 + bx + c = 0 \tag{1}$$

To proceed, they usually apply the formula expressed in Equation (2), which provides the possible solutions, without understanding its meaning graphically.

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \tag{2}$$

From this expression, it can be understood that when $b^2 - 4ac = 0$, there will be a central point on the abscissa axis (x-axis) from which there will be an equal displacement to both left and right, which will determine the cut points with the x axis ($y = 0$) as long as $b^2 > 4ac$ (so that there are real solutions). This point is called THE vertex and its component on the x axis (x_v) follows the expression presented in Equation (3).

$$x_v = \frac{-b}{2a} \tag{3}$$

Accordingly, the expression on the y-axis (y_v) will be given by the expression presented in Equation (4):

$$y_v = ax_v^2 + bx_v + c = a\cdot\left(\frac{-b}{2a}\right)^2 + b\cdot\frac{-b}{2a} + c = \frac{b^2}{4a} - \frac{b^2}{2a} + c = -\frac{b^2}{4a} + c \tag{4}$$

An example of the discussed characteristics is shown in Figure 5 for the function $y = -x^2 + 6x + 16$. This activity will attempt to discern the position of the vertex based on its expression by approximating the solution from a basic parabolic motion problem. Although students will not perform this kind of problem in physics until the first year of Baccalaureate, it will serve to acquire the basic knowledge of its operation.

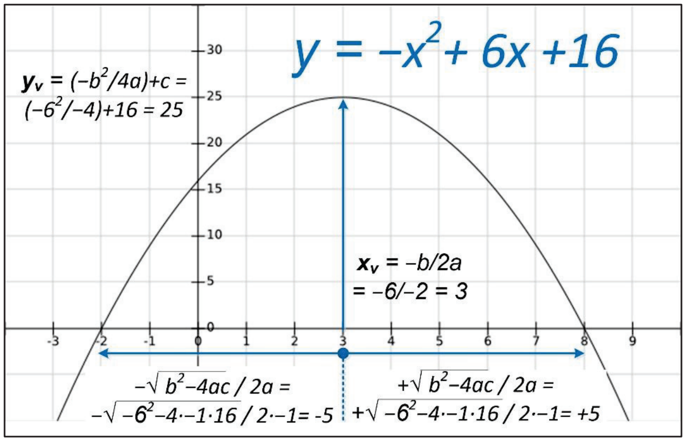


Figure 5. Quadratic function with calculation of vertex and cut-off points with x axis.

Starting from a simple *Scratch* program and a suitable scenario, the launching of a ball can be simulated by generating a parabola, as shown in Figure 6. The challenge would be to ask students to obtain adequate values for coefficients a, b and c after studying aforementioned aspects.

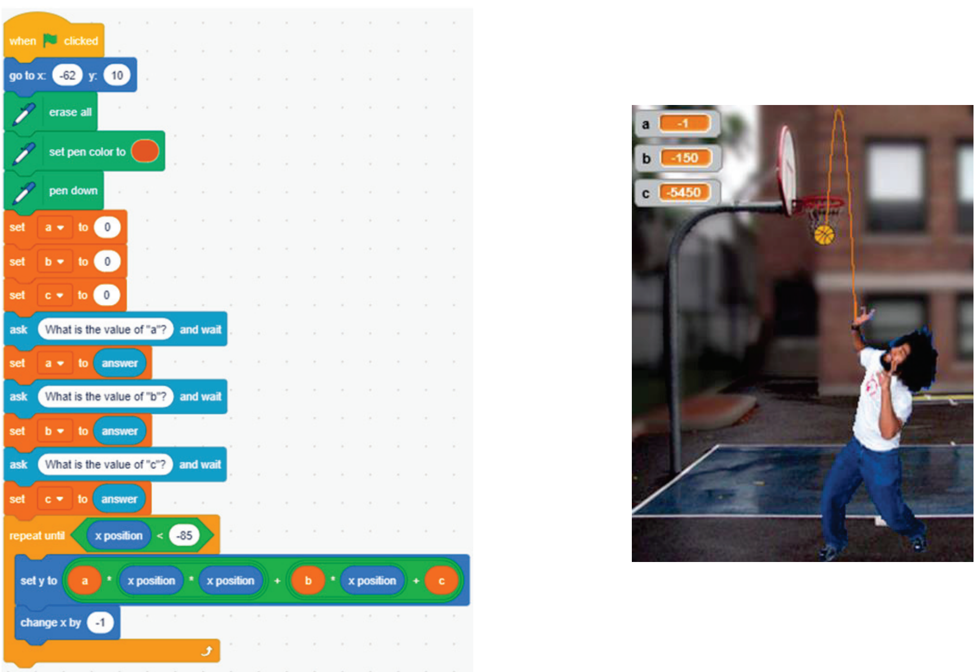


Figure 6. *Scratch* program and parabola corresponding to coefficients $a = -1$, $b = -150$ and $c = -5450$.

2.2.3. Activity 3: Infecting with Exponential Functions

In this activity, students will understand how growth works in an exponential function, which is especially striking when the exponential function growth rate seems to be low, as is the case with this problem

"Suppose a virus with a daily infection rate of 5%, this means that each day there are an additional 5% of people infected by the virus. People will continue to infect at this rate until a vaccine is found. If we assume that the days constitute the independent variable 'x' of the problem, the number of infected people the dependent variable 'y' of the problem, and that on day '0' there was only one infected person: estimate with a *Scratch* program on which day at most you could find the vaccine so that the solution of the problem is within the *Scratch* screen. Obtain also the exact solution'.

According to the proposed problem, it can be deduced that it can be expressed as presented in Equation (5).

$$y = 1.05^x \tag{5}$$

Therefore, the number of infected people depending on the number of days for some values changes dramatically when the number of days increases, as presented in Table 1.

Table 1. Infected people VS number of days.

Day	Infected People
15	2,078,928,179
150	1,507,977,496
1500	$608{,}063 \cdot 10^{31}$

- After 15 days, there are only 2 infected people;
- After 150 days, the situation could start to be alarming (1500 people infected);
- After 1500 days, "the power" of the exponential function is clearly shown: the resultant number represents 10^{21} times the world population.

The related program in *Scratch*, which is provided to students, is based on a recursive program to multiply the base of the expression (1.05), the required times by the exponent (x). The program draws with the extension "*Pen*" the area below the exponential curve, which saturates the *Scratch* screen approximately for an x = 100, as shown in Figure 7. This value can be exactly calculated applying logarithms, as presented in (6).

$$y_{max} = 1.05^{x_{max}},\ \text{where } y_{max} = 180,\ \text{so } x_{max} = \frac{\log(180)}{\log(1.05)} = 106.43, \tag{6}$$

The result of expression (6) represents the maximum day at which the vaccine could be found, so the solution of the problem within the *Scratch* screen is day 106. For this number of days, the value of y is equal to $1.05^{106} = 176.22$, which does not exceed the maximum value of the screen ($y_{max} = 180$). If an upper value is used (for example, 107), the maximum value would be exceeded ($1.05^{107} = 185.03$).

2.3. Data Collection

The data collection of the proposed activities is based on the evaluation of competences and therefore trying to identify the achievement of competencies in the student, so the objective will be to collect useful information in relation to student progress. This is key to define the assessment instruments and types.

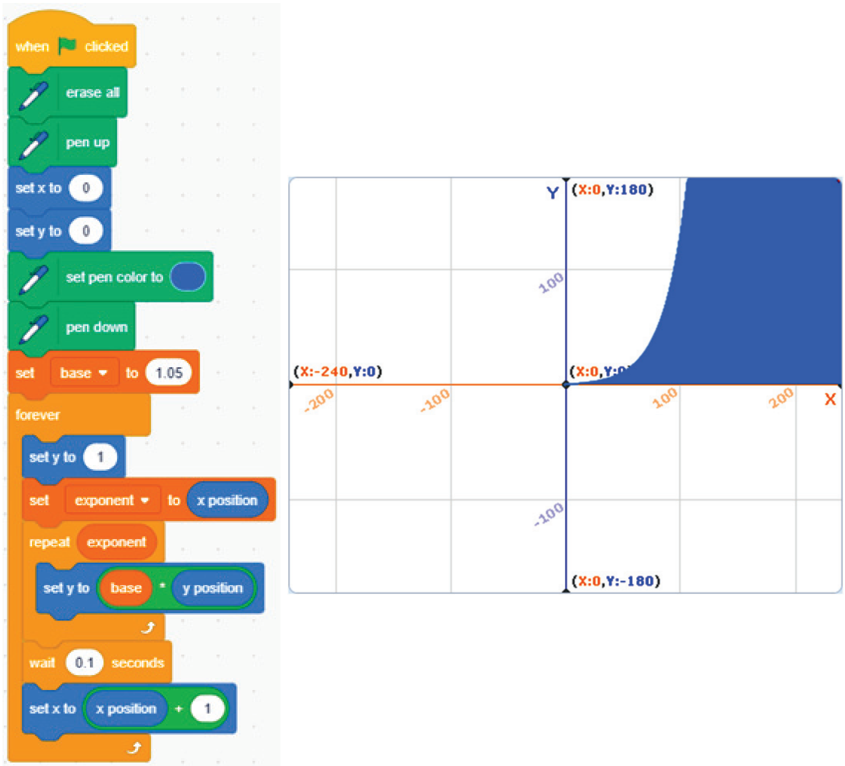


Figure 7. Scratch exponential function program. The curve saturates for $x = 107$.

2.3.1. Participants

The participants in this study were 30 future teachers. The participants are students of the Mathematics and its Didactics I subject of the first course of Primary Education Degree of the Faculty of Education Sciences (FCEDU) of the University of Las Palmas de Gran Canaria (ULPGC). From the 30 participants, 19 (63.33%) were women and 11 (36.67%) were men, all aged between 19 and 21 years old (19.2 years was the average).

Most of the participants (90%) did not know the *Scratch* programming language. All participants had no prior knowledge of teaching the functions considering the associated active methodologies.

2.3.2. Assessment Instruments

When defining the instruments for evaluating the activities carried out, the methodologies used in the teaching-learning process are also taken into account, so that they are adapted in a consistent manner. Thus, the considered instruments are the following:

- Observation: Starting from an adequate planning and systematization of evidence collection based on the work completed in a cooperative way. Students also act as observers, through a process of co-evaluation;
- Portfolio: Although the realization of the proposed activities is carried out in pairs or in trios, the portfolio is presented at two levels:
  - *Group*: Students would include *Scratch* programs of the activities carried out in a work folder, as well as a report indicating how they have developed it, highlighting the most relevant aspects;

– *Individual*: Each student would also prepare for each activity a short report which includes comments and reflections on the work completed. A self-evaluation of the work completed is also included in a self-assessment report.

- Standardized test: At the end of the activities' development, an individual standardized test will be proposed to the students, based on multiple choice reagents and a single closed response. It is intended to evaluate competences of understanding and application of terminology and methods and procedures, thus checking that the student has understood the activity both in its development and the related conclusions. Provided that the computer resources of the center are sufficient, a computer can be used by each student. Thus, for example, using the *Kahoot!* program (see example in Figure 8), reagents can be presented including images and videos if required, offering immediately the final result.

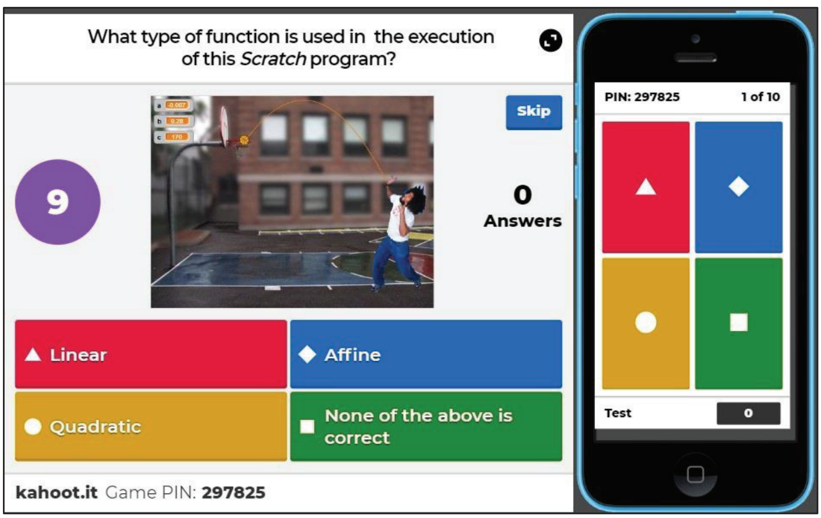


Figure 8. Question related to activities developed with *Kahoot!* software.

2.3.3. Assessment Types

The considered assessment types [28] are the following:

- **Summative assessment:** To make a decision on the qualification that the student deserves;
- **Formative assessment:** To determine the skills acquired by the student and help him to obtain mastery of competencies.

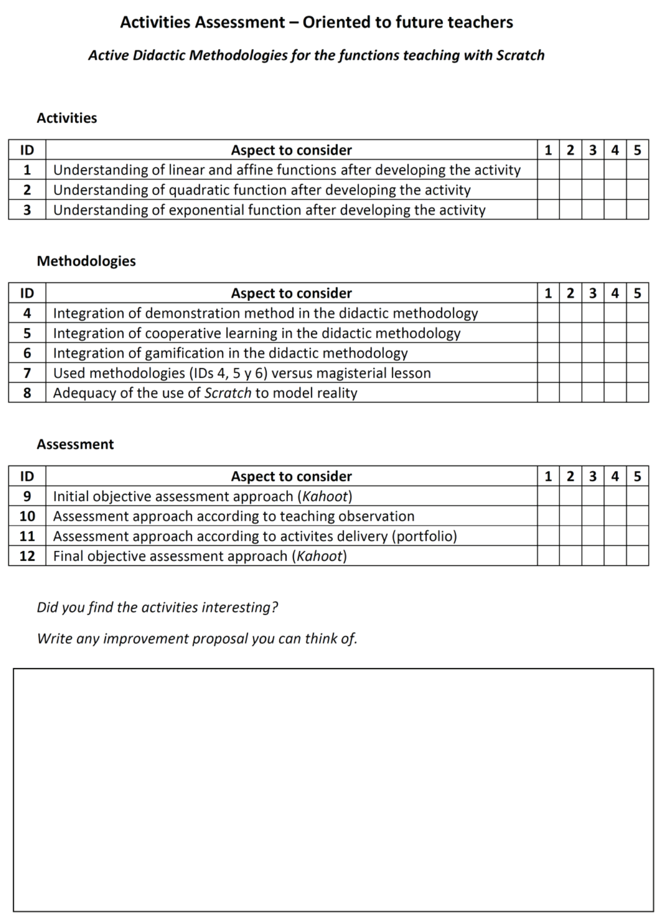
As a first step, an initial evaluation is proposed to determine the previous knowledge of the students. Likewise, during the development of the activities a continuous evaluation will be carried out based on the portfolio review, to conclude with a final evaluation. To sum up, a synthesis of the collection of evidence for the activities' assessment is presented in Table 2.

2.3.4. Considered Survey

After carrying out the considered activities and the assessment presented in Table 2, the survey shown in Figure 9, based on a 5-point Likert scale (1: strongly disagree; 2: disagree; 3: neither agree nor disagree; 4: agree; 5: strongly agree), was passed to the students.

Table 2. Synthesis of evidence collection and weighted evaluation.

Indicator	Objective Test External Assessment (Teacher)	Self-Report Self-Evaluation (Student)	Questionnaire Co-Evaluation (Pairs)	Observation External Assessment (Teacher)
Develop an activity with *Scratch* related to a function type	Nº items: 10 Items type: multiple choice (4 alternatives) Correction: Sum of correct answers	Portfolio (with respect to activity: individual and group)	Activity presentation in class (questionnaire)	Portfolio (with respect to activity: individual and group)
Moments of information collection	Beginning and end of the activities	Beginning and end of the activities	End of the activities	Beginning, 50% and end of the activities
Summative assessment weighting	20	25	25	30
Formative assessment weighting	30	-	20	30



Activities Assessment – Oriented to future teachers

Active Didactic Methodologies for the functions teaching with Scratch

Activities

ID	Aspect to consider	1	2	3	4	5
1	Understanding of linear and affine functions after developing the activity					
2	Understanding of quadratic function after developing the activity					
3	Understanding of exponential function after developing the activity					

Methodologies

ID	Aspect to consider	1	2	3	4	5
4	Integration of demonstration method in the didactic methodology					
5	Integration of cooperative learning in the didactic methodology					
6	Integration of gamification in the didactic methodology					
7	Used methodologies (IDs 4, 5 y 6) versus magisterial lesson					
8	Adequacy of the use of *Scratch* to model reality					

Assessment

ID	Aspect to consider	1	2	3	4	5
9	Initial objective assessment approach (*Kahoot*)					
10	Assessment approach according to teaching observation					
11	Assessment approach according to activites delivery (portfolio)					
12	Final objective assessment approach (*Kahoot*)					

Did you find the activities interesting?

Write any improvement proposal you can think of.

Figure 9. Proposed survey.

The survey was designed ad hoc by the authors for this research. Three key aspects related to the second research question were taken into account: the activities, the methodologies and the assessment. The questionnaire consisted of 12 questions, and since the three aspects were equally important, the same number of questions were assigned for each aspect—that is, four questions for each of the three aspects.

To validate the reliability of the survey as suitable data collecting instrument, Cronbach's alpha method was considered, obtaining a value of 0.79. This score is assessed as adequate according to authors such as Nunnally [29], who states that a value of 0.5 or 0.6 would be sufficient for early stages of a research. Other authors, such as Huh et al. [30], consider that this reliability value should be equal or higher than 0.6 in exploratory research. Therefore, the survey used as an instrument in this paper counts on a high reliability rate.

3. Results

The survey results are presented in Table 3. The results show an average higher than 4 in all questions, highlighting the understanding of linear and affine functions (4.57) and quadratic functions (4.4) as well as the averages of activities (4.36) and assessment (4.35).

Table 3. Survey results. Partial results for activities, methodologies and assessment together with the total are included.

Theme/Question Number	Average
Activities (Global 1–3)	**4.36**
1	4.57
2	4.40
3	4.10
Methodologies (Global 4–8)	**4.17**
4	4.07
5	4.07
6	4.33
7	4.17
8	4.23
Assessment (Global 9–12)	**4.35**
9	4.30
10	4.27
11	4.43
12	4.40
Total (All Questions)	**4.28**

The presented results show that students found the activities motivating. They understand that the combination of the proposed methodologies is an appropriate alternative to the magisterial lesson. Each theme is further analyzed in the Discussion section.

4. Discussion

In the following subsections, the results are discussed considering previous works and including the proposals for improvement commented by the students.

4.1. Activities

Students assessed activities by giving a maximum punctuation to activity 1 (average: 4.57), then activity 2 (average: 4.4) and finally activity 3 (average: 4.1). According to these results and students' comments in the class, it seems that the first activity, based on linear and affine functions, was quite attractive to them since it was clear and simple.

However, the understanding of the exponential function and the use of a recursive function to translate it into *Scratch* was more difficult to them and probably this is the reason of the survey result in this case. In fact, recursion and fractal thinking usually require more time and better tools, and scaffolds linking fractals and fractal thinking to the curriculum and the real world, as concluded by Lee and Jian in a recent study related to the assessment of computational thinking in *Scratch* fractal projects [31]. On the other hand, the modelling of the quadratic function in a context related to basketball has been also successful in the past in several scenarios, for instance, using a video of a trajectory as an initial step and concluding if it represents a parabola [32]. In our proposal, the originality of finding the required function coefficients in a *Scratch* environment motivated students to find not only one possible solution, but the optimum.

4.2. Methodologies

All considered methodologies were well assessed, especially highlighting gamification (average: 4.33). It is remarkable that students consider that the use of the considered methodologies is better than the magisterial lesson (average: 4.17) and that the use of *Scratch* is appropriate to model reality (average: 4.23). While students require the integration of active methodologies, it is important to note that there are still teachers who cling to their old magisterial lessons because they are afraid that if they abandon the teaching style that they know, they will lose control of the class. Consequently, it is key to orient the training of teachers on the positive pedagogical effects the new style would render: co-operative work and problem solving or research, among others, instead of only focusing towards the purely technical aspects [33]. Moreover, as perceived by students, *Scratch* is appropriate to model real-life scenarios. In fact, previous studies have shown that teachers feel that it is easy to connect programming to other teaching and learning activities in school, such as problem solving. However, sometimes there is a lack of directives for the integration, in terms of what type of programming should be implemented [34]. In this sense, it is important to know *Scratch* limitations and when another programming language, such as Python, should be used as an alternative.

4.3. Assessment

The different proposals included in the assessment were similarly accepted, with slight differences in the average results: 4.43 (portfolio), 4.4 (final objective assessment), 4.3 (initial objective assessment) and 4.27 (teaching observation). In this case, it is clear that the main motivation for the students is the realization of the *Scratch* activities which conform the portfolio. This *Scratch* portfolio approach was originally proposed as a possibility by Mitch Resnick and Karen Brennan. In this case, each member of the *Scratch* online community has a profile page. In this page, any member (scratcher) can display creations as well as other dimensions of participation, such as scratchers they follow. The teacher analyzes the portfolio of projects uploaded by a particular community member (student). This approach is specially focused on the development of computational thinking through *Scratch* programming activities [35]. In this sense, previous research of Permatasari et al. showed that more than 90% of learning outcomes were achieved following a portfolio assessment using a problem-based learning model with *Scratch* in the last cycle of the sequence. In this way, portfolio represented the main assessment tool with respect to pre-action testing and attitude observation [36].

4.4. Proposals for Improvement

The students indicated the following aspects as proposals for improvement:

- More time for its approach given the complexity of the program for some of them. It is observed that since they had not practiced before with *Scratch*, it was difficult to them to understand the program, which contrasts with the experience at an early age. From here, the importance of integrating programming at an early age is deduced, as with languages or any type of practical learning;

- Ask students to complete a program with *Scratch*, based on everything learned with these activities;
- The evaluation with *Kahoot!* was very well received, although it was indicated that the images shown should be highlighted to make their visualization easier.

4.5. Limitations and Future Research Lines

Although we have found interesting results, this study presents some limitations. On the one hand, the study sample is not very large. However, for a first exploratory study, it provides relevant information in the research context (Faculty of Education Sciences of the University of Las Palmas de Gran Canaria). On the other hand, the qualitative study may be enhanced considering additional instruments. Future works will extend the sample, also considering qualitative assessment instruments such as structured interviews.

Future research lines include the combination of the presented aspects with robotics, based on platforms such as *Scratch for Arduino* as well as the usage of other programming languages in different education levels.

5. Conclusions

The objective of this paper is to study the *Scratch* programming language as a didactic tool to teach functions and analyze the suitability of different methodologies to teach functions.

In this paper, we presented three innovative activities aimed at the block of functions of the subject of mathematics. The starting point was the use of *Scratch* software to didactically introduce the linear, affine, quadratic and exponential functions. The proposed activities were combined with active didactic methodologies in order to make the most of them, proposing at the same time a coherent assessment.

The proposed activities were introduced to a group of 30 students of the Mathematics and its Didactics I subject of the Primary Education Degree of the Faculty of Education Sciences (FCEDU) of the University of Las Palmas de Gran Canaria (ULPGC). The activities, methodologies and assessment were evaluated by these students with results higher than 4 in Likert scale for all cases, showing a preference for the proposed methods over the magisterial lesson. Students especially highlighted simple activities based on linear and affine functions as well as the use of gamification methodology and the assessment based on portfolios. Even though some students found the program complex, asking for more time to understand it, they also found it motivating, asking for additional activities on everything learned.

Author Contributions: Conceptualization, E.Q.G.; methodology, E.Q.G. and A.Z.L.; software, E.Q.G.; validation, E.Q.G. and A.Z.L.; formal analysis, E.Q.G. and A.Z.L.; investigation, E.Q.G.; resources, E.Q.G. and A.Z.L.; data curation, E.Q.G. and A.Z.L.; writing—original draft preparation, E.Q.G.; writing—review and editing, E.Q.G. and A.Z.L.; visualization, E.Q.G. and A.Z.L.; supervision, E.Q.G. and A.Z.L.; project administration, E.Q.G. and A.Z.L.; funding acquisition, E.Q.G. and A.Z.L. 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: Data available on request.

Acknowledgments: We would like to thank the group "Innovación Educativa en Diseño e Implementación de Sistemas Integrados (GIE-56)" of the University of Las Palmas de Gran Canaria and the educational innovation project "ROBOT-EDULPGC. Diseño, implementación y puesta en práctica de una plataforma modular de robótica educativa de bajo coste (PIE2020-56)" for their collaboration in this study.

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

References

1. Valovičová, L.; Ondruška, J.; Zelenický, L.; Chytrý, V.; Medová, J. Enhancing Computational Thinking through Interdisciplinary STEAM Activities Using Tablets. *Mathematics* **2020**, *8*, 2128. [CrossRef]
2. Bocconi, S.; Chioccariello, A.; Dettori, G.; Ferrari, A.; Engelhardt, K. *Developing Computational Thinking in Compulsory Education, Implications for Policy and Practice*; Publications Office of the European Union: Luxembourg, 2016.
3. Wing, J. *Computational Thinking: What and Why?* The Link, The magazine of Carnegie Mellon University's School of Computer Science: Pittsburgh, PA, USA, 2010; pp. 1–6.
4. Forman, G.; Pufall, P.B. *Constructivism in the Computer Age*; Lawrence Erlbaum Associates: Mahwah, NJ, USA, 1988.
5. Papert, S.; Harel, I. *Constructionism*; Ablex Publishing Corporation: New York, NY, USA, 1991.
6. Marji, M. *Learn to Program with Scratch*; No Starch Press: San Francisco, CA, USA, 2014.
7. Corralero, N. *Scratch*. Programación fácil para educación primaria y secundaria [Easy programming for primary and secondary education]. *Rev. Digit. Soc. Inf.* **2011**, *29*, 1–10.
8. Chiang, F.; Qin, L. A Pilot study to assess the impacts of game-based construction learning, using *scratch*, on students' multi-step equation-solving performance. *Interact. Learn. Environ.* **2018**, *26*, 803–814. [CrossRef]
9. Resnick, M.; Maloney, J.; Monroy-Hernández, A.; Rusk, N.; Eastmond, E.; Brennan, K.; Kafai, Y. *Scratch*: Programming for All. *Commun. ACM* **2009**, *52*, 60–67. [CrossRef]
10. Vázquez-Cano, E.; Ferrer Delgado, D. La creación de videojuegos con *Scratch* en educación secundaria [Videogamescreation with *Scratch* in secondary school]. *Commun. Pap.* **2015**, *4*, 63–73. [CrossRef]
11. Valle, J.E.M.; Salgado, V.C. Pensamiento lógico matemático con *Scratch* en nivel básico [Mathematical-logical thinking with *Scratch* at a basiclevel]. *Vínculos* **2013**, *9*, 87–95.
12. Quevedo-Gutiérrez, E.G. Robot Position in the Cartesian Coordinate System: A Didactic Proposal. In *Playing and Learning Using Robotics among University Students*; Galstyan-Sargsyan, R., Belda-Torrijos, M., López-Jiménez, P.A., Pérez-Sánchez, M., Eds.; Nova Science Publishers Inc.: New York, NY, USA, 2019; pp. 61–74.
13. Rodríguez-Martínez, J.A.; Rodríguez-Calero, J.A.; Saéz-López, J.M. Computational thinking and mathematics using *Scratch*: An experiment with 6th-grade students. *Interact. Learn. Environ.* **2019**, *28*, 316–327. [CrossRef]
14. Shahbari, J.A.; Daher, W.; Baya'a, N.; Jaber, O. Prospective Teachers' Development of Meta-Cognitive Functions in Solving Mathematical-Based Programming Problems with Scratch. *Symmetry* **2020**, *12*, 1569. [CrossRef]
15. Baccaglini-Frank, A.E.; Santi, G.; Del Zozzo, A.; Frank, E. Teachers' Perspectives on the Intertwining of Tangible and Digital Modes of Activity with a Drawing Robot for Geometry. *Educ. Sci.* **2020**, *10*, 387. [CrossRef]
16. Quevedo-Gutiérrez, E.G.; Hernández, V.M.; Quevedo-Sarmiento, J.R.; Zapatera-Llinares, A. Lenguaje de Programación *Scratch* como Herramienta Didáctica para la Enseñanza del Sistema de Coordenadas Cartesianas en Educación Primaria [*Scratch* Programming Language as a Didactic Tool to Learnthe Cartesian Coordinate System in Primary School]. *Form. Profr. Investig. Educ. Matemática* **2017**, *12*, 187–202.
17. Fuentes-Cabrera, A.; Parra-González, M.E.; López-Belmonte, J.; Segura-Robles, A. Learning Mathematics with Emerging Methodologies—The Escape Room as a Case Study. *Mathematics* **2020**, *8*, 1586. [CrossRef]
18. Vega-Moreno, D.; Quevedo, E.; Llinás, O.; Hernández-Brito, J. Project—based learning using robots with open—source hardware and software. In Proceedings of the II Jornadas Iberoamericanas de Innovación Educativa En El Ámbito de Las TIC, Las Palmas de Gran Canaria, Spain, 12–13 November 2015; pp. 141–144.
19. Ramadhan, N.; Surya, E. The Implementation of Demonstration Method to Increase Students' Ability in Operating Multiple Numbers by using Concrete Object. *Int. J. Sci. Basic Appl. Res.* **2017**, *34*, 62–68.
20. Salmerón, H.; Gutiérrez-Braojos, C.; Rodríguez, S.; Salmerón, P. Influencia del aprendizaje cooperativo en el desarrollo de la competencia para aprender a aprender en la infancia [Influence of cooperative learning in the development of the learning how to learn competence in childhood]. *Rev. Esp. Orientac. Psicopedag.* **2010**, *21*, 308–319. [CrossRef]
21. Johnson, D.W.; Johnson, R.T. Cooperative Learning. School Improvement Programs. In *A Handbook for Educational Leaders*; Block, J.H., Everson, S.T., Guskey, H., Eds.; Scholastic Inc.: New York, NY, USA, 1995; pp. 25–26.
22. Zichermann, G.; Cunningham, C. *Gamification by Design: Implementing Game Mechanics in Web and Mobile Apps*; O'Reilly Media: Cambridge, UK, 2011.
23. Díez-Rioja, J.; Bañeres-Besora, D.; Serra-Vizern, M. Experiencia de gamificación en Secundaria en el Aprendizaje de Sistemas Digitales [Gamification experience in secondary school for digital systems learning]. *Educ. Knowl. Soc.* **2017**, *18*, 85–105. [CrossRef]
24. Delgado-Gómez, D.; González-Landero, F.; Montes-Botella, C.; Sujar, A.; Bayona, S.; Martino, L. Improving the Teaching of Hypothesis Testing Using a Divide-and-Conquer Strategy and Content Exposure Control in a Gamified Environment. *Mathematics* **2020**, *8*, 2244. [CrossRef]
25. Swacha, J. State of Research on Gamification in Education: A Bibliometric Survey. *Educ. Sci.* **2021**, *11*, 69. [CrossRef]
26. Zamora, Á.; Ardura, D. ¿En qué medida utilizan los estudiantes de Física de Bachillerato sus propios errores para aprender? Una experiencia de autorregulación en el aula de secundaria [To what extent do high school physics students use their own mistakes to learn? An experience on self-regulation in a secondary school classroom]. *Enseñanza Cienc.* **2014**, *32*, 253–268.
27. Santana, R. Situación de Aprendizaje: El Cartesiano. [Learning Situation: The Cartesian Coordinate System]. Consejería de Educación y Universidades, Gobierno de Canarias. Available online: https://www3.gobiernodecanarias.org/medusa/ecoescuela/sa/2014/09/02/el-cartesiano/ (accessed on 20 August 2021).

28. Jornet-Meliá, J.M.; Martínez-Sánchez, A. *Aprendizaje y Enseñanza: Aspectos Comunes a las Especialidades [Learning and Teaching: Common Aspects to Specialities]*; Universidad Internacional de Valencia: Valencia, Spain, 2018.
29. Nunnally, J.C. *Psychometric Theory*; McGraw-Hill: New York, NY, USA, 1967.
30. Huh, J.; DeLorme, D.E.; Reid, L.N. Perceived third-person effects and consumer attitudes on prevetting and banning DTC advertising. *J. Consum. Aff.* **2006**, *40*, 90–116.
31. Lee, C.S.; Jiang, B. Assessment of Computational Thinking (CT) in Scratch Fractal Projects: Towards CT-HCI Scaffolds for Analogical-fractal Thinking. In Proceedings of the 11th International Conference on Computer Supported Education (CSEDU), Heraklion, Crete, Greece, 2–4 May 2019; pp. 192–199.
32. Schubert, M.; Ludwig, M. Modeling quadratic functions in the schoolyard. In Proceedings of the Research on Outdoor STEM Education in the digiTal Age (ROSETA), Porto, Portugal, 16–19 June 2020; pp. 155–162.
33. Lara, S. Preparing Teachers and Schools for the 21st Century in the Integration of Information and Communication Technologies. Review of Recent Report in the U.S. *Interact. Educ. Multimed.* **2006**, *12*, 44–61.
34. Humble, N.; Mozelius, P.; Sällvin, L. Remaking and reinforcing mathematics and technology with programming—Teacher perceptions of challenges, opportunities and tools in K-12 settings. *Int. J. Inf. Learn. Technol.* **2020**, *37*, 309–321. [CrossRef]
35. Bilbao, J.; Olatz-García, C.R.; Bravo, E.; Varela, C. Different Types of Assessments for implementation of Computational Thinking. *Int. J. Educ. Learn. Syst.* **2018**, *3*, 27–31.
36. Permatasari, L.; Yuana, R.A.; Maryono, D. Implementation of *Scratch* Application to Improve Learning Outcomes and Student Motivation on Basic Programming Subjects. *J. Inform. Vocat. Educ.* **2019**, *2*, 53–59. [CrossRef]

education sciences

MDPI

Article

Brazilian and Spanish Mathematics Teachers' Predispositions towards Gamification in STEAM Education

Paula López [1,*], Jefferson Rodrigues-Silva [1,2] and Ángel Alsina [1]

[1] Department of Specific Didactics, University of Girona, 17080 Girona, Spain; jeffe.rodri@gmail.com (J.R.-S.); angel.alsina@udg.edu (Á.A.)
[2] Department of Mechanical Engineering, Federal Institute of Minas Gerais, Belo Horizonte 30000-000, MG, Brazil
* Correspondence: paula.lopez@udg.edu; Tel.: +34-972-418-332

Abstract: This article reports a multiple case study in which we analyse Brazilian and Spanish mathematics teachers' opinions about and predispositions toward gamified activities in STEAM education. To obtain data, we administered a survey to 56 in-service mathematics teachers in primary and secondary education from these countries. The survey had been previously validated throughout an expert judgement process. Our results show a high percentage of teachers who think this kind of activity has positive effects on students' development, improving their affective domain toward mathematics and required skills for mathematical competency. Notwithstanding, many teachers report insecurity and lack of training for employing such educational methodologies.

Keywords: teacher predispositions; gamification in education; gamifying learning; STEAM education; mathematics; Brazil; Spain

Citation: López, P.; Rodrigues-Silva, J.; Alsina, Á. Brazilian and Spanish Mathematics Teachers' Predispositions towards Gamification in STEAM Education. *Educ. Sci.* **2021**, *11*, 618. https://doi.org/10.3390/educsci11100618

Academic Editors: José Carlos Piñero Charlo, María Teresa Costado Dios, Enrique Carmona Medeiro, Fernando Lloret and James Albright

Received: 10 August 2021
Accepted: 5 October 2021
Published: 9 October 2021

1. Introduction

Fostering students' motivation, engagement, and behavioural changes is an appealing objective that researchers argue the gamification of education could achieve [1–4]. Additionally, it seems desirable to educate people with interdisciplinary knowledge and develop skills and abilities for autonomously and critically acting, living, and working in a complex and ever-changing twenty-first-century world, which is promised by STEAM Education—an interdisciplinary approach among the areas of Science, Technology, Engineering, Arts and Humanities, and Mathematics [5]. Therefore, we could conjoin these goals by thinking of gamification as an educational strategy for pursuing and promoting STEAM Education [6], for example, in mathematics [7].

STEAM Education has recently become a trend in educational development [8] that promotes learning throughout and for the interdisciplinary enterprise [5]. We find it across all educational stages: from early childhood education until higher education [4,9]. Originally, the term STEAM derived from the acronym STEM [10]. The National Science Foundation (NSF) in the 1990s formalised the acronym STEM concerning the four areas of Science, Technology, Engineering, and Mathematics [11]. Afterward, STEAM Education emerged as a new pedagogy during the Americans for the Arts-National Policy Roundtable discussion in 2007 "to help counterbalance the increased focus on STEM subjects and the decline in arts education in the U.S." [10] (p. 32).

STEAM has cognitive and affective objectives, namely STEAM Literacy [12], and also democratic and utilitarian goals (skill development) [13]. STEAM is based on educational philosophies such as Deweyan pragmatism and the premise that learning should be constructed through (reflection about) experience [14]. The term STEAM aligns well with many methods [5] especially active and collaborative ones, e.g., the maker movement, Project Based Learning (PjBL), Problem Based Learning (PBL) [8], augmented reality [15], and gamification [6].

Gamification is a neologism derived from the digital media field [16]. The first use of this concept, in 2003, is attributed to Nick Pelling, a British game developer. [1]. Although gamification is a relatively young topic, it is an increasing research interest topic [2,3]. A bibliometric survey showed the geographic distribution of research in the gamification of education: from 100 countries, the United States of America has the largest share of publications on the subject (almost 13%), while Spain comes closely behind with almost 9%; the results placed Brazil in the fifth position in the list (4.2%) [4].

Deterding et al. [17] (p. 02) define gamification as "the use of game design elements in a non-game environment". Although there is no consensus of a specific definition and scope for gamification, according to the literature review, the definition from Deterding et al. [17] is the most widespread and accepted [1,18]. Among these game elements, we encounter reward-action contingency (RACs): leader boards, scoring, and badges [19]. Additionally, mission, narrative, character, level, aim, resources and items, and collaboration are game elements applied in learning gamification [18]. However, if we have applied game elements, how does gamification work in a non-game environment? One major difference between gamification and designing conventional games remains because we apply gamification regarding some desired outcomes from a particular context, while also providing some enjoyment. The latter has internal objectives concerning pure entertainment [18].

Mora et al. [18] found in a literature review of 40 publications generic framework designs for gamification (35%) and frameworks for specific contexts, which they categorised as business (45%), learning (15%), and health (5%). Hamari et al. [2] found empirical studies of gamification in various contexts. In this paper, we address studies of gamification in the educational context.

In education, gamification is reported as a powerful tool for teachers at all levels in the educational system [1]. Hamari et al. [2] reviewed the literature in empirical studies of gamification and observed that educational context was the most reported. All articles reviewed reported learning outcomes as mostly positive: increasing motivation, engagement, and enjoyment. Additionally, gamification encourages extracurricular and interdisciplinary learning [1]. Mora et al. [18] acknowledged a consensus that design frameworks in education explicitly reveal the importance of defining clear objectives. Gamification differs conceptually from serious games in this aspect. Serious games immerse learners into the gameplay and attempt to hide educational objectives. In gamification, educational objectives are visible [1]. According to the literature, researchers commonly report unclear objectives as the main reason for failure in gamification designs [18].

The literature suggests gamification as an active method for STEAM education. Cleophas [6], for example, reported a case study of STEAM-gamified activity employed in Brazil. She designed and applied it using many game elements, such as score, a classification table, and progress feedback. She included content knowledge of the history and fundamentals of chemistry: chemical bonds, formulas, stoichiometric balance, reactions, and ammonia synthesis. She pointed to interdisciplinarity within STEAM areas: including poetry and caricature (Arts) and chemical calculations and logic association (Mathematics). The author considered that the activity also involved technology and engineering, although she treated them as resources and not proper knowledge areas. Technology was referred to as the use of technological tools, mobile applications and social media, and engineering simply as applying manipulative material for constructing molecules. Cleophas [6] argued that the STEAM gamified approach permitted graduating challenges, promoting spaces for feedback, motivating and engaging students, and fostering collaboration among them.

Mendes et al. [20] reviewed gamification applied to teaching deaf students and related to learning sign language. They note that this usage was reported in few countries, e.g., Brazil, Egypt, and Romania. According to them, gamification is in its commencement as an inclusive strategy, but it has already been shown as an avenue for creating communication systems between deaf people and deaf people and listeners through sign language.

In mathematics education, as an area that is part of STEAM education, gamification is present from the first educational levels [21,22] and throughout all the stages, especially in secondary education [23]. Computer science, social sciences, engineering, and mathematics are, in this order, the most reported areas in the gamification of education [4]. However, gamification in mathematics is sometimes misconceived, and the term gamification is improperly used in the description's framework and/or the analysis of games. Muñoz et al. [24] points to four key characteristics that should be met in a gamified activity in mathematics: (1) it proposes a problem to be individually or collaboratively solved to achieve rewarded objectives; (2) it creates challenges between users; (3) it accounts for scores, so that students receive gifts or prizes; and (4) it creates levels and rankings so that students can receive feedback, compete, and compare their results. These indicators maintain strong links with an approach to teaching mathematics through mathematical processes of problem-solving, reasoning and proof, communication, connections, and representation, more linked to thinking and doing than to memorising concepts and reproducing procedures [25].

Based on a review of gamified activities in mathematics, we find several digital games where students have to perform tests to achieve a goal using technological devices, e.g., mobile phones [26–28]. Jagušt et al. [1] (p. 451), for example, reported an empirical study about a gamified lesson using tablets in lower primary mathematics classes in competitive, adaptive, and collaborative conditions. Compared to the control group, non-gamified activity, "three other gamified conditions showed positive trends in terms of several solved tasks as time passed, with the adaptive condition being the most prominent, followed by competitive and collaborative conditions". Notwithstanding, the adaptive condition was statistically significant as causing the greatest amount of stress among students and led to the greatest number of incorrect task competition attempts. The authors also re-examined error role in education, arguing that gamification may provide a welcoming ambience for incorrect answers in the initial phases, and this strategy can be effective for learning.

Despite the excitement around gamification, there is some controversy. Mora et al. [18] observed that some frameworks consider using technology as a prerequisite for gamification, while some researchers support that "[g]amification can also be done completely offline by adding motivational narratives as a prequel to an activity or by awarding paper badges or medals for certain educational achievements" [1] (p. 456). In this sense, gamification could be associated with object-based learning (OBL) [29], wherein manipulative materials play a pedagogical role. Most frameworks of gamification address fun as a relevant aspect to be considered during the design process of gamification. Issues such as risk, feasibility, and investment are often disregarded [18]. It is worth remarking that Dubbels [19] argues that gamification is reported as easy or expensive to construct, compared to game design.

Hamari et al. [2] pointed out that some studies showed that the results of gamification may not be long term, but caused by a novelty effect. A decrease in students' motivation and satisfaction over time has been reported, comparing gamified with non-gamified courses [1]. Muñoz et al. [24] warned that repetition of this type of activity ends up causing boredom in students, whom we intend to motivate a priori. Disengaged students are powerfully motivated when facing something new, but as soon as they have to apply the knowledge they still do not have, and if they do not promptly learn with these activities, these students end up disconnecting quickly. Others reported possible negative outcomes that need to be paid attention to, such as increasing competition, task evaluation difficulties, and design features. It seems that gamification alone may not sustain the effects on students' interest, motivation, and satisfaction levels [1].

Studies and experiences with escape rooms have also proliferated [30–32], which again present the same problem: it creates great expectations when used for the first time, but since we cannot repeat it, once its features become known, it loses the initial potential for motivation. This type of activity also has the disadvantage of requiring much work to be prepared, and then it is hard to be adapted to other students or other contents. This does not happen when using games in mathematics class, as it has been implemented for decades.

The existing literature addresses true gamification in learning mathematics, while some experiences misconceive gamification in mathematics by referring to it when concerning game usage in education. Additionally, the previously commented upon inconsistencies and controversies found around the subject should be considered. Altogether, this also leads to a requirement for investigation into teachers' opinions, since they are indeed agents with a relevant role in teaching. Studies have analysed teachers' beliefs about gamification, and they have found that teachers have positive opinions about it [33–35]. For example, students develop learning, skills, and the affective domain [33,34] in a gamified teacher training course [35]. Notwithstanding, there are practically no studies in Spain and Brazil that have analysed the effect of implementing gamification as a tool to promote mathematics learning and instruction. Concerning gamification, Alabbasi [34] concluded that teachers have a positive perception of incorporating it into online learning. They consider, for example, that gamification improves students' motivation towards course goals, elevates students' satisfaction, and promotes the urge to go beyond the requirements of the course. It increases attention and the curiosity to navigate multiple elements in the learning management system [34].

STEAM Education research also lacks an understanding of teachers' beliefs [36–38]. Kim and Bolger [36] remark that despite Korean teachers considering that STEAM educational programs can have a positive impact on elementary education, many are reluctant to take part in STEAM education. Teachers' negative perception of STEAM education is mainly justified by their belief in insufficient training and experience [36]. Teachers may have different perceptions of interdisciplinary approaches, e.g., secondary teachers who exhibit a more negative view of the potential impact of STEM education on student achievement when compared to primary teachers [38]. Among the concerns, teachers report an increase in their workload, difficulty in coordinating with teachers from other knowledge areas [38], and a lack of support from peers and school administration [37].

Considering the background described and these gaps in the literature, this study aims to analyse the predisposition of mathematics teachers in primary and secondary education to carry out gamification activities in STEAM education.

2. Materials and Methods

This is a multiple case study [39], employed as descriptive research with a mixed design: a quantitative and a qualitative part, which are interrelated in the way that one complements the other.

2.1. Participants

Participants of the study are 56 mathematics teachers, 24 being in-service in Brazil and 32 in Spain. They work with students whose average age ranges from 10 to 16 years old. Table 1 summarises sample distribution by gender and education level for both countries.

Table 1. Research sample of Spanish and Brazilian teachers was distributed per gender and education level.

Gender/Education Level [1]	Spain		Brazil	
	Primary School (10–12 Years)	Secondary School (12–16 Years)	Primary School (10–14 Years)	Secondary School (14–16 Years)
Woman	8	13	7	8
Man	4	7	2	7
Total	12	20	9	15

[1] Original education level names of primary school and secondary school in Spain, Educación Primaria and Educación Secundaria, and in Brazil, Ensino Fundamental and Ensino Médio, respectively.

Teachers working in primary school and secondary school have an average age around 50 years old and 40 years old, respectively, for both countries, Brazil and Spain. Concerning their degrees, in Spain, the primary school teachers had graduated with the specific formation of Primary Educator Teacher, except for one female teacher who had graduated in Pedagogy. Spanish Secondary School teachers' titles vary more: Mathematics (6), Engineering (5), Economics or Business Management (4), Architecture (3), Pedagogy (1), and Chemistry (1). In Brazil, Primary School teachers had graduated in Mathematics (4), Pedagogy (3), History (1), and Geography (1), and the teachers' trainings in Secondary School were in Mathematics (11), Chemistry (1), Law (1), Biology (1), and Engineering (1).

2.2. Data Collection

To collect data, we used a survey named "Gamification and Learning" (original name in Spanish "Gamificación y Aprendizaje"), proposed and validated by Cornellà [40]. According to Cornellà [40], the survey was validated though an expert judgment process, which included 17 experts. These people were distributed as experts in games and gamification (3), teachers with experience in applying gamification (7), experts in virtual learning environments (4), and experts in technology (3). The experts evaluated the adequacy between each block title and its questions, questions' relevance, and Likert scale adequacy. Cornellà [40] did corrections until the experts finally approved the survey.

We used Cornellà's [40] survey with few adaptations regarding our research objectives. For instance, we addressed gamification in mathematics in a general scope rather than focusing on virtual learning environments, as was originally the case. In addition, we included some questions related to STEAM Education.

It is noteworthy to say that the whole survey and its attachments were available in the language for each population sample: Catalan language for Spain (Catalonia Autonomy Community) and Portuguese language for Brazil. We divided the survey into three blocks.

Block A) These questions were designed to gather information about sample characteristics—age, courses, education level in which they work, and degree. Open-ended questions about prior experiences with gamification and STEAM Education were also included, so we could explore it qualitatively [41].

Block B) Two questions were included: the first is a Likert-type question scaled from 1 (not important) to 5 (very important), with a list of 18 general aspects regarding teaching the discipline of mathematics (e.g., content knowledge, ability to connect with students, method used in class, and others). In the second Likert question, teachers answered their (dis)agreement, ranging from 1 (strongly disagree) to 5 (strongly agree), to 21 statements about gamification in mathematics and interdisciplinary STEAM environment. Additionally, they evaluated a gamified activity framed in STEAM Education based on the activity Snap Hotels of Nguyen [42].

Block C) Four open-ended questions were included that were intended to explore other aspects that would permit identifying and evaluating teachers' predisposition and difficulties they consider they might encounter while employing activities in the interdisciplinary STEAM environment and/or gamified activities: (1) Teachers' beliefs about learning outcome differences between employing gamified and non-gamified activities. (2) Difficulties teachers believe they may encounter while engaging in a gamified activity. (3) Predisposition about using gamification in the next course. (4) How teachers envision the possibility of gamification in an interdisciplinary approach with STEAM areas.

2.3. Data Analysis

We analysed the Likert-type (close-ended) survey questions with descriptive statistics using frequency percentages for each item of scale. We used the R Studio Statistics program and its Likert library. This program exports data in the format of a horizontal bar graph, which permits observing respondents' positive and negative evaluation tendencies, but also neutral answer frequency, which makes it possible to perform group comparisons and address the occurrence of socially derisible responses (SDR) [43].

Analysis of the qualitative part of the study was based on constant comparisons according to grounded theory [41]. The following levels of analysis were considered. First, one author of this manuscript began by reading teachers' responses to become familiar with the content. Then, based on our research goal, we organised and structured information. At this first level, individual transcripts were arranged based on unit fragmentation or segmentation. While reading answers, teachers' dispositions to using gamification mathematics in education were noticed. For example: "*It motivates me a lot to think about implementing gamification in my class. I think it will arouse students' interest and passion*" (ProfEsp30). Raw data were transformed into useful data by first classifying and coding them.

Second, we established a group of categories. For example, in the first category, views of teachers were collected on how they use gamification in mathematics education. In this sense, the codification and categorisation of data were triangulated by comparing, ordering, and structuring to establish categories that allowed data to be compared.

Additionally, third, categories were renamed by the authors of the research, using the method of constant comparisons [41], which includes comparisons made between similarities, differences, and connections of the data. Units of information were scrutinised to see whether they clearly fell into a specific category. We further reflected on whether categories could be simplified and then grouped. We also considered the names and content of changed units, showing new relationships and possible new interpretations between categories. Thus, all aspects that prevented the definition of teachers' predispositions towards the use of gamification in mathematics education were renamed, eliminated, or simplified.

Again, it is worth noting that qualitative data were obtained in Catalan and Portuguese languages. Afterwards, these data were analysed by researchers who are native speakers of each one of these languages, so participants' original intentions could be better interpreted and captured in the analyses.

3. Results

The results follow the same order from the data collection instrument. According to the aim of our study, we analysed mathematics teachers' predispositions to carrying out gamification activities within STEAM education in primary and secondary school levels. First, we present results about the teachers' prior experiences in engaging in gamified activities and STEAM Education (Block A). Second, we present the results of closed-ended questions (Likert scale) in the form of two graphs: one about teachers' evaluations of the importance of general aspects related to classes of mathematics, and another graph about gamification in mathematics and an interdisciplinary STEAM environment. Additionally, they evaluated a gamified activity framed in STEAM Education based on the activity Snap Hotels of Nguyen [42] (Block B). Third and last, we wrote the results from analyses of four open-ended questions about gamification and STEAM Education (Block C). We present these results in the form of four tables (one referring to each question) structured with the names of corresponding categories in the first column; examples of teachers' response excerpts to qualify them in the second column; and columns with the quantification of the frequency that those categories appear in responses from Spain and Brazil.

3.1. Teachers' Prior Experiences with Gamified Activities and STEAM Education (Block A)

In this section, we present results about teachers' prior experiences with gamification in the current academic year. We present Table 2, which quantifies the proportion of teachers from Spain and Brazil who indicate having (or not having) conducted gamified activities in classes of mathematics in the current academic year (2020–2021 academic year or 2021 academic year in the Spanish or Brazilian calendar, respectively). In Spain, almost half of the total of teachers (46.9%) indicated they applied gamification in this academic year, with a higher frequency in the primary school (58.3%) compared to secondary school level (40%). In Brazil, on the other hand, the proportion of the country's total teachers who used gamification as a method in their classes in this academic year is a little more than a third (37.5%), with a much lower frequency in primary School (22.3%), which was less than half compared to the secondary school level (46.7%).

Table 2. Teachers who have previously carried out gamified activities in mathematics.

Have Carried out a Gamified Activity	Spain			Brazil		
	Primary School (10–12 Years)	Secondary School (12–16 Years)	Total	Primary School (10–14 Years)	Secondary School (14–16 Years)	Total
Yes	58.3% (7)	40% (8)	46.9% (15)	22.3% (2)	46.7% (7)	62.5% (15)
No	41.7% (5)	60% (12)	53.1% (17)	77.8% (7)	53.3% (8)	37.5% (9)
Total	12	20	32	9	15	24

A subsequent open-ended question asked for further explanation about the nature of the gamified activity from those teachers who positively answered to having applied one. In Spain, teachers reported that they applied gamification activities related to different resources and contexts: for example, a games table (2), online games (3), contests (2), and escape rooms (3). In Brazil, teachers mainly show that they employed table games (2) or online games (2). It should also be noted that around 16% of Spanish (5) and Brazilian (4) teachers considered gamification as manipulated didactic material, e.g. tangrams or multilink.

The proportion of teachers who indicated that they have worked with gamified activities in an interdisciplinary STEAM Education is much lower, as shown in Table 3: only 10 Spanish (31.2%) and 3 Brazilian (12.5%) teachers. Again, a subsequent open-ended question asked teachers to explain the nature of the gamified activities they applied within STEAM Education. In Spain, five teachers pointed to the STEAM areas they combined, while the other half did not specify. In Brazil, one teacher showed integrating mathematics and chemistry, while the others did not give more information. In addition, many have described STEAM without characteristics of gamification: for example, in the statement "*we photographed different objects in the school, then we analysed them and define each format and volume encountered*" (ProfSpain28).

Table 3. Teachers who have previously carried out gamified activities in mathematics framed in STEAM Education.

Have Carried out a Gamified Activity in STEAM Education	Spain			Brazil		
	Primary School (10–12 Years)	Secondary School (12–16 Years)	Total	Primary School (10–14 Years)	Secondary School (14–16 Years)	Total
Yes	33.3% (4)	30% (6)	31.3% (10)	11.1% (1)	13.3% (2)	12.5% (3)
No	66.7% (8)	70% (14)	68.8% (22)	88.9% (8)	86.7% (13)	87.5% (21)
Total	12	20	32	9	15	24

3.2. Teachers' Opinions about General Aspects of Math Class regarding Gamification and STEAM Education and Evaluating an Example of a STEAM Gamified Activity (Block B)

We present results from this subtopic in the form of graphs plotted in the R Studio Statistics program for Brazil and Spain combined. Following this, we address additional considerations about differences between the countries.

Figure 1 refers to a graph with Brazilian and Spanish teachers' evaluations of the importance of general aspects related to classes of mathematics. Before observing the graph content, it is worth explaining that each line in the graph is vertically organised. Additionally, each line contains a bar which may be dislocated from the central position according to how participants evaluated that corresponding element (Likert Scale 1 to 5): a high frequency of "Slightly important" and "Not Important" (1 and 2) make this line appear on the bottom of the graph, dislocating its bar to the left, and a high frequency of positive answers "Important" and "Very important" (4 and 5) makes this line appear on top of the graph and tends to dislocate its bar to the right, and this frequency percentage is shown on this side. The percentages of positive (4 and 5), neutral (3), and negative (1 and 2) answers are shown on the vertical axes in the left, middle, and right positions of the graph.

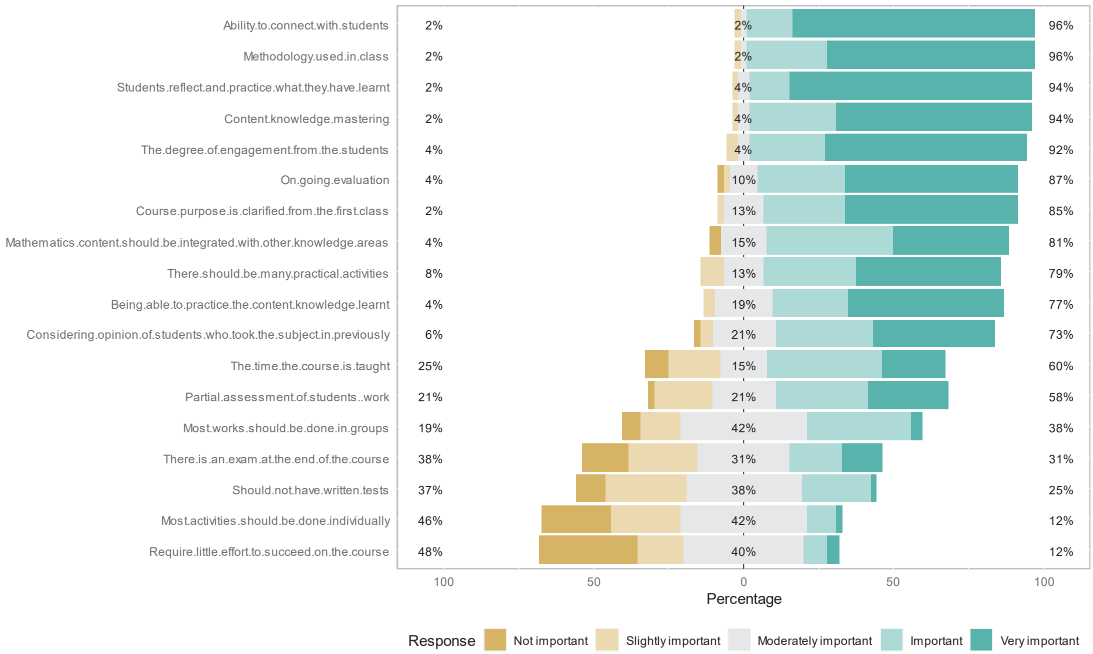


Figure 1. Brazilian and Spanish teachers' evaluation in the importance of general aspects related to classes of mathematics.

Finally, we address the content of the graph from Figure 1. First, we highlight aspects that teachers predominantly considered "Important" or "Very important": Ability to connect with students (96%), Methodology used in class (96%), Students reflect and practice what they have learnt (94%), Content knowledge mastering (94%), Students' engagement (92%), On-going evaluation (87%), Course purpose is clarified from the first class (85%), Mathematics content should be integrated with other knowledge areas (81%), There should be many practical activities (79%), Being able to practice the content knowledge learnt (77%), Considering the opinion of students who took the subject previously (73%), The time the course is taught (60%), and Partial assessment of students' work (58%).

The neutral answer "Moderately important" had a higher frequency percentage in the aspect Most works should be done in groups (42%), while it still presented a tendency towards a positive evaluation of importance (48%) compared to the negative pole (19%). In addition, the neutral answer had a slightly superior frequency in the aspect "Should not have written tests" (38%), but with a tendency towards a negative evaluation of importance (37%).

Teachers predominantly considered the following aspects "Not important" to "Slightly important": Requires little effort to succeed on the course (48%), Most activities should be done individually (46%), and There is an exam at the end of the course (38%).

Now, we draw attention to all items with a high frequency of the neutral answer "Moderately important". It had a frequency higher than 30% in the aspects Most works should be done in groups (42%), Most activities should be done individually (42%), Require little effort to succeed on the course (40%), Should not have written tests (38%), and There is an exam at the end of the course (31%).

In Figure 2, we present a graph with 21 statements about gamification in mathematics and the interdisciplinary STEAM environment. Additionally, a gamified activity framed in STEAM Education based on the activity Snap Hotels of [42] is evaluated. The graph construction and its structure are similar to Figure 1, with the difference that Likert scale refers to (dis)agreement to statements from each line, ranging from "Strongly disagree" (1) to "Strongly agree" (5).

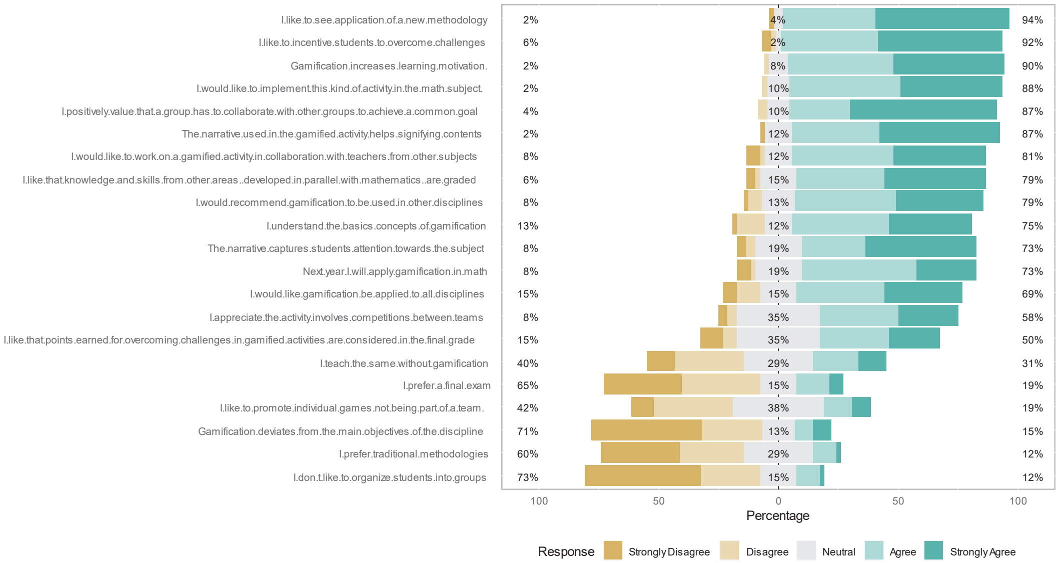


Figure 2. Teachers' opinions about gamification in mathematics and STEAM Education. Additionally, evaluation of a gamified activity framed in STEAM Education based on the activity Snap Hotels of Nguyen [42].

Teachers predominantly answered "Agree" or "Strongly agree" (4 and 5) to the statements: I like to see application of a new methodology (94%), I like to incentivize students to overcome challenges (92%); Gamification increases learning motivation (90%); I would like to implement this kind of activity in math subjects (88%); I positively value that a group has to collaborate with other groups to achieve a common goal (87%); The narrative used in the gamified activity helps signifying contents (87%); I would like to work on a gamified activity in collaboration with teachers from other subjects (81%); I like that knowledge and skills from other areas, developed in parallel with mathematics, are graded (79%); I would recommend gamification to be used in other disciplines (79%); I understand the basic concepts of gamification (75%); The narrative captures students' attention towards the subject (73%); Next year I will apply gamification in math (73%); and I would like gamification to be applied to all disciplines (69%). However, the following two statements still conserve a frequency tendency on the agreement pole: I appreciate the activity involves competitions between teams (58%) and I like that points earned for overcoming challenges in gamified activities are considered in the final grade (50%); it is worth noting the high frequency of the neutral answers, both of which were 35%.

From the bottom of the graph, we observe the statements to which teachers more frequently answered "Disagree" and "Strongly Disagree" (1 and 2). These statements include I do not like to organise students into groups (75%); Gamification deviates from the major objectives of the discipline (71%); I prefer a final exam (65%); I prefer traditional methodologies (60%); I like to promote individual games (not being part of a team) (42%); and I teach the same without gamification (40%).

Highlighting a high frequency of neutral answers, as reported above, the statements from the agreement pole I appreciate the activity involves competitions between teams and I like that points earned for overcoming challenges in gamified activities are considered in the final grade both had a 35% frequency of neutral answers. Some statements from the disagreement pole also had a high frequency of neutral answers: I like to promote individual games (not being part of a team) (38%); I prefer traditional methodologies (29%); and I teach the same without gamification (29%). No statement presented a frequency of neutral answers higher than the options of agreement or disagreement.

3.3. Teachers' Opinions about the Contrast between Gamified and Non-Gamified Activities, Issues in Gamification, and Gamification in STEAM Education (Block C)

Finally, yet importantly, we describe the results of the analyses of answers of four open-ended questions from Block C. We present these results in the form of four tables (one per question): the first column includes categories; the second column examples of teachers' response excerpts; and finally, columns with the frequency of responses from Spain and Brazil. These questions, presented below, intended to explore and identify what mathematics teachers' think about the differences between gamified and non-gamified activities, the difficulties of gamification in mathematics, their predisposition toward employing gamification, and how they envision the possibility of gamification in an interdisciplinary approach with STEAM areas.

1. Which differences do you think may exist between learning outcomes and learning processes when we compare a gamified and a non-gamified activity?

The analysis of answers to this question resulted in three principal categories of teachers' beliefs about the differences between gamified and non-gamified activities, as seen in Table 4. In the category Positive difference, around 81.1% of Spanish and 76.9% of Brazilian teachers considered differences by pointing to the advantages of gamification. On the other hand, and with a much lower frequency, in the category Negative difference, around 8.11% of Spanish and 3.85% of Brazilian teachers also considered the existence of differences, but in this case, pointing to the disadvantages of gamification. Additionally, third, in the category Not different, a few teachers considered no differences between gamified and non-gamified activities, 2.7% in Spain and no teacher from Brazil. The percentage of non-respondents in Brazil is more than double that of Spain: 19.2% and 8.11%, respectively.

Table 4. Teachers' beliefs about learning outcome differences between employing gamified and non-gamified activities.

Gamified versus Non-Gamified Activity		Teachers' Answers Excerpts	Frequency per Country	
			Spain	Brazil
Positive view towards gamification	Affective domain	"I believe student's interest makes them more open to rules, content and listening to teacher and colleague" (ProfBra20).	32.4%	34.2%
	Cognitive domain	"The difference remains in a manner to approach to content: students who learn with gamification have better memorisation and good memories about how they have learnt" (ProfEsp05).	10.8%	11.4%
	Skills acquisition	"Gamified activity enables logical reasoning skills development, contextualisation and interdisciplinarity" (ProfBra19).	27%	26.2%
	Did not specify	-	10.8%	3.85%
No differences		"They [gamified and non-gamified activities] are just methodologies, which can address content (vehicle). I do not think using one would be better than the other" (ProfEsp07).	2.7%	-
Negative view towards gamification		"Gamifying means providing time to students to build knowledge autonomously, make questions, analyse alternatives. Theoretically that is great, but it creates difficulties" (ProfEsp16).	8.11%	3.85%
Did not answer		-	8.11%	19.2%

Within the category Positive differences, we could induce subcategories regarding differences related to Affective domain, Cognitive domain, Skills acquisition, and Not Specified. The frequencies of these subcategories are similar between Spain and Brazil, aspects of Affective domain and Skills acquisition being present in approximately 30% of responses, and around 10% from the subcategory Cognitive domain.

2. Which difficulties do you believe one may face while engaging in a gamified activity in mathematics?

The results of the analysis of responses to this question resulted in the creation of four categories of issues, as displayed in Table 5, that teachers indicate are related to employing gamified activities in mathematics: Planning difficulties, Class management difficulties, Deficient teacher training, and Educational community reticence.

Table 5. Difficulties teachers believe they may encounter while engaging in a gamified activity.

Beliefs about the Difficulty in Gamified Activity in Mathematics	Teachers' Answer Excerpts	Frequency per Country Spain	Brazil
Planning difficulties	"The required time complete it in class. If the class duration is of one hour, often there is no time to finish the activity. Many centres have limited resources" (ProfEsp05).	34.3%	34.6%
Class management difficulties	"Some students may dislike it, or get too anxious/nervous; others might be so competitive that they have to be redirected" (ProfEsp06).	25.7%	11.5%
Deficient teacher training	"Little teachers' experience while designing gamified activities and managing tools that would facilitate this task" (ProfEsp11).	20%	19.2%
Educational community reticence	"Breaking with traditional approaches: the biggest difficulty is being open to novelty since it means a greater expenditure of energy, many teachers will think like that" (ProfBra11).	-	15.4%
Did not answer	-	20%	19.2%

As a result, we detected some discrepancies between Brazil and Spain. Although the similarity in the frequency of respondents who pointed to issues within planning difficulties was approximately 34%, when we scrutinise the responses, we noticed differences. With Brazil, half of these responses suggested a lack of resources/investment as an issue when employing gamification in mathematics, e.g., in the excerpt: "*Since I work in a public school, we deal with limited resources. Frequently I spend my money to apply games or other methodologies*" (ProfBra20). Spanish teachers centred their attention on difficulties with the design and evaluation of gamified activities.

In the second category, Class management difficulties, the content of answers is similar for the countries, but it is more prominent with Spain, where the frequency is more than double that of Brazil: 25.7% and 11.5%, respectively.

We highlight another difference between the studied countries in the category Educational community reticence. A significant proportion of Brazilian teachers, 15.4%, show they are likely to face some reticence among peers or the scholar board when employing non-traditional educational methodologies such as gamification. Meanwhile, no Spanish respondent demonstrated this kind of difficulty.

Similarly, with around 20% of response frequency, Brazilian and Spanish teachers show Deficient teacher training as a difficulty in pursuing gamification in their classes. Approximately 20% of Brazilian and Spanish teachers did not answer this question.

3. How do you evaluate the possibility of using gamification as a teaching method in classes of mathematics? What are your feelings about it?

We could classify the answers from these questions into the categories Favourable predisposition and Unfavourable predisposition regarding teachers' intentions to attain gamification in their disciplines. Inside the category Favourable predisposition, we could distinguish three subcategories, as shown in Table 6, that qualify this predisposition: without indicating reticence, with reticence about deficient teacher training, and with reticence about lack of resources.

Table 6. Teachers' predisposition about using gamification in the next course.

Predisposition		Teachers' Answer Excerpts	Frequency per Country Spain	Brazil
Favourable	Not indicating major concerns	"It motivates me a lot to think about implementing gamification in my class. I think it will arouse students' interest and passion" (ProfEsp30).	43.8%	54.2%
	but showing insecurity or concerns about lack of formation	"I want it, but it generates in me some sense of losing control. Perhaps, gradually, it can be achieved" (ProfEsp23). "I would love it, but I am conscious I should receive training previously" (ProfEsp19).	34.4%	8.33%
	but showing concerns about lack of resources	"Again we face the difficulty of time and investments" (ProfBra22).	-	4.17%
Unfavourable		Little possibility regarding the pandemic scenario (ProfBra03).	-	8.33%
Did not answer		-	21.9%	25%

Most teachers, approximately 70% for both countries, who replied to this question show a favourable predisposition to employing gamification in their classes. Some of them, on the other hand, question this predisposition. For instance, 34.4% of Spanish teachers suggest that teacher training would be necessary, while in Brazil, only 8.33% pointed in this direction. Again, lack of resources/investment appears to be an issue that differentiates the countries, since only Brazilian teachers, 4.17%, showed a favourable predisposition but reticence considering this reason. Only Brazilians answered with an unfavourable predisposition, with an 8.33% frequency of responses in this country, e.g., justified by the pandemic scenario of COVID-19: "*I see little possibility, given the current pandemic scenario*" (ProfBra03).

4. How do you evaluate, in a gamified activity, the possibility of providing an interdisciplinary environment with some (or all) STEAM areas?

We categorised the results of this question into Possible and Not possible, referring to providing STEAM interdisciplinary environments through gamification. Most teachers in Brazil, 81.8%, envision this possibility, while in Spain, the percentage is 50%, as shown in Table 7.

Table 7. Teachers' beliefs about providing STEAM interdisciplinary environments throughout gamification as a teaching method.

Gamification as a Method for STEAM Education	Teachers' Answers Excerpts	Frequency per Country Spain	Brazil
Possible	"It is a good idea to evaluate when next academic year begins" (ProfEsp32).	50.0%	81.8%
Not possible	"Little possibility, since there is a curriculum to be accomplished" (ProfBra03).	28.1%	9.09%
Did not answer	-	21.9%	9.09%

Those who replied no possibility presented justifications for being sceptical about this association of gamification and STEAM Education, such as deficient teacher training—"*Currently, I see it impossible. It would be necessary to train all teachers before working collaboratively and in a multidisciplinary approach*" (ProfEsp05) —being difficult to assess—"*It is complex to know what to be evaluated and where it focuses on each discipline*" (ProfEsp07) —

difficulty in coordinating different disciplines, especially in the secondary school level—"*It requires much coordination and sometimes it is hard to gather*" (ProfEsp22) —or lack of adequate time—"*Feasible, but I imagine that organising it requires time that we don't have*" (ProfEsp15). In Spain, we also observed teachers from primary school, who regularly already have the same professional teaching subjects from different knowledge areas, evaluate this possibility more positively. Half of the teachers from secondary school did not see it as possible because, among the difficulties mentioned before, they found it hard to coordinate along with teachers in other STEAM areas.

4. Discussion

In this article, we analysed teachers' opinions and predispositions about gamified activities and the STEAM education approach. According to the literature review, mathematics is one of the STEAM areas that has been least considered so far in gamification (4). Studies of gamification in mathematics have mainly focused on the effect of this method on students' learning outcomes [21–24,28], reporting data, to some extent divergent, related to students' engagement, motivation, or satisfaction [1,2,24].

However, what is the role of mathematics teachers' predispositions and opinions towards gamification? What effects can those teachers' predispositions and opinions have on students' levels of engagement, motivation, and satisfaction? As previously shown, few studies in the literature address teachers' opinions and predispositions about the use of gamification in mathematics classes [33–35], and even fewer in the Spanish and Brazilian panorama.

Data from our study help to fill this literature gap. The first revealing result is that only half of the Spanish teachers and two-thirds of the Brazilian teachers who took part in our study have used gamification in mathematics. Important differences between the two countries emerge when we observe gamification. With Spain, teachers employed a wider variety of resources; comparing students' ages, while in Spain, they apply gamification more in the primary school compared to secondary school level, in the Brazilian context, it happens the other way around.

The results confirm increasing academic attention towards both gamification and competency-based education [33]. Currently, it appears slightly more palpable in Spain than in Brazil. The number of Spanish and Brazilian teachers who have worked with gamification within the STEAM Education approach is much lower, also observing some confusion around the concepts of both gamification [24,25] and STEAM.

Regarding teachers' opinions about using gamification, mathematics teachers at primary and secondary schools in both countries have highlighted that they consider mastery of content as essential in gamified activities, as well as other elements such as reflective and critical thinking skills [33] or engagement [34]. One aspect mathematics teachers least valued was that activities should be done individually in gamification. These data reinforce the findings of Martí-Parreño et al. [33] and Allabasi [34], which suggest that teachers believe gamification encourages team working and oral communication skills, along with social interaction.

Our findings address how mathematics teachers perceive differences and difficulties while using gamified activities within the STEAM Education approach, compared to more traditional ones. The results show, at first sight, a high percentage of teachers (around 80%) who think this kind of activity has positive effects on students' development, improving their affective domain toward mathematics and required skills for mathematical competency. Based on teacher opinions, we can complement the results from previous studies about students' affective domain, which suggests gamification alone may not sustain students' interest and motivation in satisfaction levels [1]. In this sense, we can add that gamification could be carried out in STEAM Education. In order for those features of the affective domain to be more highly attained, this approach to gamified activities needs to be authentic to provide an interdisciplinary environment.

Since teachers believe gamification in a STEAM approach promotes skills development for mathematical competency, we found the congruency that both teachers and policy makers should be encouraged to increase the use of gamification-based programs to develop students' competencies [33]. Concerning the main difficulties, we observed similarities and differences between the two studied populations: teachers from both countries misunderstand the concepts of gamification and STEAM, and they indicate insecurity and a lack of training in planning gamified activities, which points to the necessity for specific teacher training programs [35,36].

In the Brazilian case, half of the teachers refer to the lack of resources as the reason for not carrying out gamification in their classes, but we recall from the literature that gamification can be done with low investment in resources [19]. Since these teachers reported almost no prior experiences with gamification, and those few who reported included examples of activities that are not considered gamification, such as the use of manipulative objects, this leads to the interpretation that this complaint about lack of resources might be a clue about a misunderstanding of the concept of gamification.

Still focusing on the Brazilian context, teachers showed concerns about reluctance/resistance from teaching staff or school management when they want to carry out activities with methodologies such as gamification. Therefore, this seems to show that experts should design teacher training within models that consider the transformation of teachers' beliefs, such as with the realistic-reflective training model [44], to address this resistance.

Finally, in our study, we have also investigated teachers' predispositions to carrying out gamification activities in interdisciplinary environments with STEAM disciplines. The results from a closed-ended question show that around 80% of Brazilian and Spanish teachers agreed with the statements "*I would like to work on a gamified activity in collaboration with teachers from other subjects*" and "*I like that knowledge and skills from other areas, developed in parallel with mathematics, are graded*". Notwithstanding, further exploration in an open-ended question showed that this same favourable disposition of 80% only remained for Brazil. In Spain, there are differences between primary teachers, who are generalists and teach all STEAM subjects, and secondary teachers, who are specialists and only teach mathematics. In primary school, teachers see it as possible, but in secondary, more than half of the teachers do not see it as possible because they find it difficult to coordinate with teachers from other STEAM areas. This result confirms the findings of Part et al. [38].

The literature about Likert scales warns that people are likely to choose neutral options for reasons other than being neutral about the topic—for example, when respondents have no interest, or when they want to provide a socially desirable response (SDR): to respond according to what they imagine others expect them to answer or to avoid options that they think peers or any reference group would frown upon [43]. Neutrality in the agreement was around 40% with questions that address students' distribution: "Most works should be done in groups" or "Most activities should be done individually". Neutrality was around one-third of the responses when we scrutinised the evaluation and the statements "Should not have written tests", "There is an exam at the end of the course", and "Points from the gamified activity to be considered in the final grade". All this points to the possibility that teachers may give an SDR of a favourable disposition towards new methodologies such as gamification when they are not sure if they agree with it. Another statement directs us to this conclusion: almost one-third of teachers responded neutrally to "I prefer traditional methodologies".

We highlight that in open-ended responses, only 43.8% of Spanish and 54.2% of Brazilian teachers stated a favourable predisposition towards gamification without reticence. Reticence, whatever its form, might underpin indisposition. Another consideration could be due to the fact that 21.9% of Spanish and 25% of Brazilian teachers did not answer, while the question straightforwardly asked them to evaluate the possibility of using gamification as a teaching method in classes of mathematics. Not answering it may also point to some indisposition.

Our results show that it seems necessary to add a fifth characteristic that should be fulfilled, so that mathematics education could be promoted through the gamification method, to those already indicated by Muñoz et al. [24]: interdisciplinarity. Since teachers present a conceptual misunderstanding of gamification and STEAM Education, they report insecurity and lack of training for engaging in such educational methodologies [33–37]. They also may have an underpinning reluctance to designing and carrying out gamified activities within interdisciplinary approaches [36]. Along with this observation of ambiguous speech in which they are theoretically favourably considering new methodologies, they also show traits of indisposition when they think about actually applying them. In conclusion, there is an urgency for designing teacher-training programs framed within models that intend to transform professional competency by reflecting on teachers' prior experiences and beliefs about gamification and STEAM Education. Therefore, we recommend researchers to explore teacher-training programs in gamification and STEAM Education within a realistic-reflective framework, considering the possibility of distance learning modalities, especially for big countries such as Brazil [45]. The results qualitatively show interesting insights into teacher perceptions on gamification and STEAM Education in the countries of Brazil and Spain. Notwithstanding, the research has a limitation: the sample is small, and therefore the comparative results between the two populations cannot be generalised. Further studies with larger samples are necessary.

Author Contributions: Conceptualization, J.R.-S. and Á.A.; methodology, P.L. and Á.A.; formal analysis, P.L. and J.R.-S.; writing—original draft preparation, J.R.-S., P.L. and Á.A.; writing—review and editing, P.L., J.R.-S. and Á.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

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

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

References

1. Jagušt, T.; Botički, I.; So, H.J. Examining competitive, collaborative and adaptive gamification in young learners' math learning. *Comput. Educ.* **2018**, *125*, 444–457. [CrossRef]
2. Hamari, J.; Koivisto, J.; Sarsa, H. Does Gamification Work?—A Literature Review of Empirical Studies on Gamification. In Proceedings of the Annual Hawaii International Conference on System Sciences, Waikoloa, HI, USA, 6–9 January 2014; pp. 3025–3034. [CrossRef]
3. Dichev, C.; Dicheva, D. Gamifying education: What is known, what is believed and what remains uncertain: A critical review. *Int. J. Educ. Technol. High. Educ.* **2017**, *14*, 9. [CrossRef]
4. Swacha, J. State of research on gamification in education: A bibliometric survey. *Educ. Sci.* **2021**, *11*, 69. [CrossRef]
5. Yakman, G.; Lee, H. Exploring the Exemplary STEAM Education in the U.S. as a Practical Educational Framework for Korea Georgette. *Korea Assoc.* **2012**, *32*, 1072–1086.
6. das Cleophas, M.G. Integração Entre a Gamificação e a Abordagem Steam no Ensino de Química. *Rev. Educ. Do Val. Do São Fr.* **2020**, *10*, 78–109. Available online: https://periodicos.univasf.edu.br/index.php/revasf/article/view/1087 (accessed on 10 August 2021).
7. Udjaja, Y.; Guizot, V.S.; Chandra, N. Gamification for Elementary Mathematics Learning in Indonesia. *Int. J. Electr. Comput. Eng. IJECE* **2018**, *8*, 3860. [CrossRef]
8. Lin, C.L.; Tsai, C.Y. The Effect of a Pedagogical STEAM Model on Students' Project Competence and Learning Motivation. *J. Sci. Educ. Technol.* **2021**, *30*, 112–124. [CrossRef]
9. MacDonald, A.; Murphy, S.; Danaia, L. *Across the Learning Continuum*, 1st ed.; Springer Nature: Singapore, 2020. [CrossRef]
10. Perignat, E.; Katz-Buonincontro, J. STEAM in practice and research: An integrative literature review. *Think. Ski. Creat.* **2019**, *31*, 31–43. [CrossRef]
11. Catterall, L. A Brief History of STEM and STEAM from an Inadvertent Insider. *Steam* **2017**, *3*, 1–13. [CrossRef]
12. Zollman, A. Learning for STEM Literacy: STEM Literacy for Learning. *Sch. Sci. Math.* **2012**, *112*, 12–19. [CrossRef]
13. Chesky, N.Z.; Wolfmeyer, M.R. Philosophy of STEM Education: A critical investigation. In *Philosophy of STEM Education*, 1st ed.; Rud, A.G., Ed.; Palgrave Macmillan: London, UK, 2015. [CrossRef]
14. Dewey, J. *Art as Experience*; Perigee: Tracy, CA, USA, 2005.
15. Jesionkowska, J.; Wild, F.; Deval, Y. Active learning augmented reality for steam education—A case study. *Educ. Sci.* **2020**, *10*, 198. [CrossRef]

16. Bai, S.; Hew, K.F.; Huang, B. Does gamification improve student learning outcome? Evidence from a meta-analysis and synthesis of qualitative data in educational contexts. *Educ. Res. Rev.* **2020**, *30*, 100322. [CrossRef]
17. Deterding, S.; Dixon, D.; Khaled, R.; Nacke, L. From Game Design Elements to Gamefulness: Defining. In Proceedings of the International Academic MindTrek Conference: Envisioning Future Media Environments, MindTrek, Tampere, Finland, 28–30 September 2011; pp. 9–15. [CrossRef]
18. Mora, A.; Riera, D.; González, C.; Arnedo-Moreno, J. Gamification: A systematic review of design frameworks. *J. Comput. High. Educ.* **2017**, *29*, 516–548. [CrossRef]
19. Dubbels, B. Gamification, serious games, ludic simulation, and other contentious categories. *Int. J. Gaming Comput. Mediat. Simul.* **2013**, *5*, 1–19. [CrossRef]
20. Mendes, L.O.R.; Bueno, A.J.A.; da Dessbesel, R.S.; de da Silva, S.C.R. Gamificação no Processo de Ensino e Aprendizagem de Estudantes Surdos: Uma revisão sistemática. *Novas Tecnol. Na Educ.* **2019**, *17*, 142–151.
21. Cunha, G.C.A.; Barraqui, L.P.; De Freitas, S.A.A. Evaluating the use of gamification in mathematics learning in primary school children. In Proceedings of the Frontiers in Education Conference, FIE, Covington, KY, USA, 16–19 October 2019; pp. 18–21. [CrossRef]
22. Marín-Díaz, V.; Sampedro-Requena, B.E.; Muñoz-Gonzalez, J.M.; Jiménez-Fanjul, N.N. The possibilities of gamifying the mathematical curriculum in the early childhood education stage. *Mathematics* **2020**, *8*, 2215. [CrossRef]
23. Hossein-Mohand, H.; Trujillo-Torres, J.M.; Gómez-García, M.; Hossein-Mohand, H.; Campos-Soto, A. Analysis of the use and integration of the flipped learning model, project-based learning, and gamification methodologies by secondary school mathematics teachers. *Sustainability* **2021**, *13*, 2606. [CrossRef]
24. José, M.; Antonio, H.J.; Fernández-Aliseda, A. Gamificación en matemáticas, ¿un nuevo enfoque o una nueva palabra? *Epsil. Rev. Educ. Matemática* **2019**, *101*, 29–45. Available online: https://thales.cica.es/epsilon/sites/thales.cica.es.epsilon/files/epsilon101_3.pdf (accessed on 10 August 2021).
25. Alsina, Á.; Maurandi-Lopez, A.; Ferre, E.; Coronata, C. Validating an Instrument to Evaluate the Teaching of Mathematics through Processes. *Int. J. Sci. Math. Educ.* **2021**, *19*, 559–577. [CrossRef]
26. Gurjanow, I.; Oliveira, M.; Zender, J.; Santos, P.A.; Ludwig, M. *Shallow and Deep Gamification in Mathematics Trails BT—Games and Learning Alliance*; Gentile, M., Allegra, M., Söbke, H., Eds.; Springer International Publishing: Berlin/Heidelberg, Germany, 2019; pp. 364–374.
27. Lameras, P.; Moumoutzis, N. Towards the gamification of inquiry-based flipped teaching of mathematics: A conceptual analysis and framework. In Proceedings of the International Conference on Interactive Mobile Communication Technologies and Learning (IMCL), Thessaloniki, Greece, 19–20 November 2015; pp. 343–347. [CrossRef]
28. Su, C.-H. Designing and developing a novel hybrid adaptive learning path recommendation system (ALPRS) for gamification mathematics geometry course. *Eurasia J. Math. Sci. Technol. Educ.* **2017**, *13*, 2275–2298. [CrossRef]
29. Tanabashi, S. STEAM Education Using Sericulture *Ukiyo-e*: Object-Based Learning through Original Artworks Collected at a Science University Museum in Japan. *Interdiscip. J. Environ. Sci. Educ.* **2021**, *17*, e2248. [CrossRef]
30. Fuentes-Cabrera, A.; Parra-González, M.E.; López-Belmonte, J.; Segura-Robles, A. Learning mathematics with emerging methodologies-The escape room as a case study. *Mathematics* **2020**, *8*, 1586. [CrossRef]
31. Moura, A.; Santos, I.L.; Technologies, L.; Santos, I.L. *Escape Room in Education: Gamify Learning to Engage Students and Learn Maths and Languages*; University of Coimbra: Coimbra, Portugal, 2020; pp. 179–193.
32. Lathwesen, C.; Belova, N.; Medeiro, E.C.; Lloret, F. education sciences Review Escape Rooms in STEM Teaching and Learning-Prospective Field or Declining Trend? A Literature Review. *Educ. Sci.* **2021**, *11*, 308. [CrossRef]
33. Martí-Parreño, J.; Galbis-Córdova, A.; Currás-Pérez, R. Teachers' beliefs about gamification and competencies development: A concept mapping approach. *Innov. Educ. Teach. Int.* **2021**, *58*, 84–94. [CrossRef]
34. Alabbasi, D. Exploring graduate students' perspectives towards using gamification techniques in online learning. *Turk. Online J. Distance Educ.* **2017**, *18*, 180–196. [CrossRef]
35. Gómez-Carrasco, C.J.; Monteagudo-Fernández, J.; Sainz-Gómez, M.; Moreno-Vera, J.R. Effects of a gamification and flipped-classroom program for teachers in training on motivation and learning perception. *Educ. Sci.* **2019**, *9*, 299. [CrossRef]
36. Kim, D.; Bolger, M. Analysis of Korean Elementary Pre-Service Teachers' Changing Attitudes About Integrated STEAM Pedagogy Through Developing Lesson Plans. *Int. J. Sci. Math. Educ.* **2017**, *15*, 587–605. [CrossRef]
37. Boice, K.L.; Jackson, J.R.; Alemdar, M.; Rao, A.E.; Grossman, S.; Usselman, M. Supporting teachers on their STEAM journey: A collaborative STEAM teacher training program. *Educ. Sci.* **2021**, *11*, 105. [CrossRef]
38. Park, H.J.; Byun, S.Y.; Sim, J.; Han, H.; Baek, Y.S. Teachers' perceptions and practices of STEAM education in South Korea. *Eurasia J. Math. Sci. Technol. Educ.* **2016**, *12*, 1739–1753. [CrossRef]
39. McMillan, J.H.; Schumacher, S. *Research in Education: Evidence-Based Inquiry*, 6th ed.; Allyn and Bacon: Boston, MA, USA, 2006.
40. Cornellà, P. Gamificació del Aprenentatge a la Formació Inicial de Mestres. Reptes, Pistes i Claus per a Desbloquejar Metodologies. Ph.D. Thesis, Univerity of Girona, Girona, Spain, 2019.
41. Strauss, A.; Corbin, J. Grounded theory methodology: An overview. In *Handbook of Qualitative Research*; Sage Publications, Inc.: Newbury Park, CA, USA, 1994; pp. 273–285.
42. Nguyen, F. Hotel Snap. 2013. Available online: https://www.fawnnguyen.com/teach/hotel-snap?rq=hotel (accessed on 10 August 2021).

43. Matas, A. Diseño del formato de escalas tipo Likert: Un estado de la cuestión. *Rev. Electron. Investig. Educ.* **2018**, *20*, 38–47. [CrossRef]
44. Alsina, Á.; Mulà, I. Advancing towards a transformational professional competence model through reflective learning and sustainability: The case of mathematics teacher education. *Sustainability* **2019**, *11*, 4039. [CrossRef]
45. Rodrigues-Silva, J.; Alsina, Á. Formação docente no modelo realista-reflexivo. *Revista Educação Em Questão* **2021**, *59*, 1–28. [CrossRef]

education sciences

Article

Implementation of a Playful Microproject Based on Traditional Games for Working on Mathematical and Scientific Content

Alicia Fernández-Oliveras [1,*], María José Espigares-Gámez [2] and María Luisa Oliveras [3]

[1] Departamento de Didáctica de las Ciencias Experimentales, Facultad de Ciencias de la Educación, Universidad de Granada, 18071 Granada, Spain
[2] Facultad de Ciencias de la Educación, Universidad de Granada, 18071 Granada, Spain; mrjs_46@hotmail.es
[3] Departamento de Didáctica de la Matemática, Facultad de Ciencias de la Educación, Universidad de Granada, 18071 Granada, Spain; oliveras@ugr.es
* Correspondence: alilia@ugr.es

Citation: Fernández-Oliveras, A.; Espigares-Gámez, M.J.; Oliveras, M.L. Implementation of a Playful Microproject Based on Traditional Games for Working on Mathematical and Scientific Content. *Educ. Sci.* **2021**, *11*, 624. https://doi.org/10.3390/educsci11100624

Academic Editors: José Carlos Piñero Charlo, María Teresa Costado Dios, Enrique Carmona Medeiro and Fernando Lloret

Received: 16 July 2021
Accepted: 7 October 2021
Published: 11 October 2021

Abstract: According to previous research, we consider it necessary to extend the use of games, as mediating elements, in the learning of STEAM (Science, Technology, Engineering, Arts and Mathematics) contents rejected by many students. For this, we have carried out an educational research project on games, with an ethnomathematical approach, since games are an important cultural sign with mathematical and scientific potentialities. We have prepared an anthropological study and an analytical one, generating a catalogue of games from different cultures. Thus, we have verified that, starting with culture, we can get to the game, but we posed the query as to whether, starting from certain games, we could achieve enculturation, by activating mathematical and scientific content in the players. To answer this query, we have created a curricular design called "playful microproject" with three traditional games from different cultures and geographical contexts. The microproject was implemented with 32 participants, from 8 to 12 years old. To analyse the results of the microproject, a case study was carried out using qualitative methodology. As part of the playful microproject, the necessary materials for each game were made by hand, and the games were then played. Both the realization of the games and the act of playing showed evidence of mathematical and scientific content, although more in the act of playing. The results revealed that: (1) the three games mobilized 21 categories of analysis, made up of scientific-mathematical content; (2) the three games proved to be equivalent in strong didactic potential; (3) that the microproject provides a valuable intercultural educational approach. The contents evidenced constitute a fundamental part of the Primary Education curriculum: classify, organize, measure, and quantify items, as well as formulate hypotheses, draw conclusions, place oneself in space, and design strategies, among others. It is concluded that these games can promote scientific-mathematical enculturation in a contextualized way.

Keywords: game-based learning; traditional games; ethnomathematics; steam; intercultural education; primary education

1. Introduction

1.1. Background

Huizinga considered humans to be Homo Ludens or "man who plays" [1]. For this author, play is a cultural phenomenon, a social impulse that extends to all civilizations, as an essential element of each culture that subjects create and use throughout the whole of their lives [2,3]. We assume his vision and value the importance of play as a cultural sign that characterizes each social group and belongs to all humanity, as it originates with the development of society itself and leads the person towards integration into a social group [4].

Regarding the repercussions of play in each subject, its educational influence is undeniable. Play, however, is the ideal scenario for acquiring a great deal of learning. For example, some games help in the structuring of language [5], and others favours development of thinking [6]. According to Garaigordobil [7], there are a number of studies that demonstrate how play is a key part in the development of learning in children and adults. In accordance with this idea, there is currently a complete line of international research on playful learning, which includes game-based learning, on which our study focuses, centred on the educational use of traditional games.

We consider play as a key element in the development of the person, taking, as reference, the ideas of Piaget [8], where he interprets play as the means by which the child comes into contact with and develops in the environment, thereby learning to understand reality. This is somewhat related to the proposal of Vigotsky, who affirmed that the game is a social activity [9]. In consideration of these ideas, it becomes necessary to highlight that, despite their importance in current and future society, the skills associated with scientific thinking are often not developed in the classroom and, therefore, need to be promoted through educational and cultural tools, such as games [10]. To the point of taking it as a reference for an educational research project that has been taking shape for a number of years, and which has, as its precedents, various studies on play, its classifications and potential for working on mathematical and scientific content [11–13]. This project comprises four components: anthropological study, analytical study, educational study, and field research (Figure 1). A summary of the first two stages (anthropological and analytical study) can be consulted in a previous publication [14], and the final two stages are presented here.

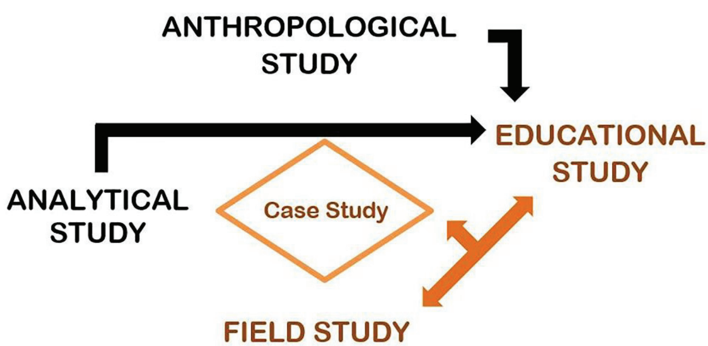


Figure 1. Project components and their relationship to the case study.

The four studies are consecutive and linked, metaphorically configuring a continuous curve. The results of the first generated the research questions of the second, and from this arises the third, focusing the attention on three paradigmatic games united in an MPL that is implemented, constituting "a case"; the fourth study takes, as an object of investigation, the case generated in the third. First, in the anthropological study, we investigated the culture, confirming that the game is one of its idiosyncratic values. We did this in the case of Jamaican culture, compiling its most popular games and discovering scientific-mathematical and social aspects of a dozen games rooted in Jamaica. Then, through a second analytical study, we studied a sample of 40 multicultural games, developing a catalogue with detailed characteristics of these games. In the final stage, we selected, from this catalogue, 3 popular games that share a common origin: the game of checkers. With these games, we conducted a third educational and a fourth research studies. We found that these games arise from broadly different socio-geographical contexts and ancestral cultures, but they are currently connected by emigration and tourism. Next, we developed a didactic proposal in the form of an Interdisciplinary Playful Microproject with the three selected games, and finally, we carried out a "Case Study" on the MPL, showing scientific-mathematical content and forms of learning that can be promoted through games. The first two studies lead from culture to games, as a circumference arc, and the two studies that we present here fit into the base of that arc and build the arc backwards: from games to culture. This leads to enculturation in mathematics and science, implicit in games, and to current interculturality based on ancestral heritage.

In the phase corresponding to the anthropological study, the first element is culture associated with play. Bishop [15] indicated that there are six types of activities carried out by all social groups. Playing is one of them. Focusing on this idea, the anthropological study of our project is pertinent, due to the nature of play, and fundamental, because our work is grounded on the research programme denominated Ethnomathematics [16–19], which investigates the relationships between mathematics and different cultures, making the existence of mathematics visible in all of them. From this focus, mathematics can be defined as a three-dimensional creation constructed by: formal science, a mode of individual thought, and social interaction [20,21]. Ethnomathematics includes these three components and is defined by several authors as follows: "Mathematics practiced between cultural groups identifiable as national tribal societies, guilds, children of a certain age, and professional classes" [22]; "A cultural product that has been developed as a result of several activities" [23]; Mathematics implicit in each practice [24], which emerge in all cultures; "modes and techniques (tics) of comprehension, grasp, and explanation of the natural and cultural setting (mathema) in different cultural systems (ethno) [25]. The literature on Ethnomathematics is currently extensive, with notable references for the present work [26–33].

Rosa & Orey [34] relate mathematics to other areas of cognition, such as language or meanings—something tremendously related to culture and its dissemination. At this point, one of the ethnomathematical principles of Gerdes [24] is noteworthy, where the importance of emphasizing the implication of sociocultural factors (game) in education, learning, and development of mathematics is addressed. That is the aim we focus our mathematical and scientific interest on, with games that offer cultural elements applicable to mathematics teaching.

Ideas that were already raised by Alsina and Planas [35], where they make a comparative analysis of the procedures involved in the game and in mathematics, some of them being: knowledge of the rules, acquiring familiarity by relating some pieces to others, making comparisons and interactions of elements, explore the procedures used by other players or discover interesting problems and solve them. Finally, mention of the reflection by Miguel de Guzmán [36] relates to the game and the teaching of mathematics through the following thought: "Mathematics has been/is art and this artistic component related to play is consubstantial to mathematical activity". That is to say, in all mathematics, there is a game, and in every game, there is mathematics.

Once the concepts of play and ethnomathematics have been identified, it is necessary to address what the analytical study consists in the classification and analysis of the games selected, focusing mainly on their mathematical and scientific aspects [37,38]. The purpose of this study is to obtain information on the potential of games for developing STEAM (Science, Technology, Engineering, Arts, and Mathematics) learning, where the arts are present in diverse forms, for example creativity, but where learning is also supported and improved in cognitive, physical, language, social, and emotional domains [39]. The term was coined by Yakman & Lee [40] as a framework for education via disciplines focused in an integrated manner. In other words, it was a new paradigm that proposes the sciences (including mathematics) and technology interpreted via engineering and the arts [41]. The complete potential of STEAM goes beyond aesthetics and takes in arts related to language, culture, history, and humanities [42]. The influence of STEAM education can be appreciated in our proposal for playful microprojects based on traditional games [43,44]. It provides a context for the learning of values that is appropriate for a project of this type, which is something that Park & Ko [45] commented on when they indicated that STEAM education should take into account integrative thinking systems, creativity, and values. Using the areas of Mathematics and Science as a starting point, we carry out the educational study, which involves the creation of the design and implementation of a playful microproject centred around three traditional games, through activities inserted into an educational model based on values of an intercultural type [46].

The field study is comprised of a case study involving the analysis of the implementation of the microproject, showing that it allows for work on scientific and mathematical content.

1.2. Game-Based Learning and STEAM Education

Recent years have seen a growing presence of creativity in education [47]. Skills relating to creativity, intellectual curiosity, critical thinking, media literacy, intercultural cooperation, and interaction are defined by experts as 21st century skills [48,49]. Teaching creatively means adopting imaginative approaches to make learning more interesting, exciting, and effective [50]. The incorporation of game-based learning strategies is a good option for putting this type of creative teaching into practice [51].

One of the objectives of the use of games at school can be the comprehension of concepts, improvement of techniques (knowledge games), or the acquisition of problem-solving methods—strategy games [52,53]. A number of different studies draw attention to the positive impact this type of learning has on reasoning capacity [54] and maths and science performance [55] Games have a positive impact on learning mathematics and attitudes toward this subject [56]. Analogous to our research, other works have proposed to use games "as a potentially useful tool to introduce and teach specific material to specific populations" [57], while another study has undertaken activities similar to our microproject [58], proposing "praxis games" founded on the concept of situated praxis.

Situated praxis encourages the design and development of games that guide players to discover knowledge inside a range of communities, domains, and experiences.

Others [11] highlight the development of skills associated with playful thinking, such as proposal of objectives, analysis of problematic situations, divergence, or generation of ideas, and convergence in practical solutions. The use of games is, therefore, a powerful tool for working on innovative thinking and developing creativity [59]. Games encourage the acquisition of basic abilities, such as those associated with learning self-regulation (learning to learn) and autonomy (personal initiative), as they provide experiences according to the demands of the player and set achievable goals that give the confidence to keep learning [60]. This, and another study [61], relates to our microproject, given that it studies the effects of the use of self-constructed materials.

Game-based learning promotes the development of social skills [62], motivation to learn [63], improvement in attention, concentration, complex thinking, and strategic planning [64].

Games even help to internalize multidisciplinary knowledge [65], foster logical and critical thinking, and develop cognitive skills associated with problem solving [66] and decision making [67].

All of the above infers the value of using games in STEAM education. However, play is not simply a methodology for intellectual learning; it is also a tool for building contexts in which students find themselves immersed, thus their integral nature and suitability for putting STEAM education proposals into practice. In this regard, López-Fernández [68] frames play in two types of spheres: socio-civic and aesthetic. The social-civic sphere includes cooperative games, given that the interests of each individual are linked to those of his or her colleagues and have a bearing on situations often ignored from an educational perspective (conflict resolution, consensus). Regarding the aesthetic sphere, taking advantage of the creativity that originates in play, it concerns developing creative taste and capacity, and there is emphasis on games relating to construction, roles, and drama. These games mobilize creativity because they suppose the completion of diverse tasks and the solving of specific problems: building a house, making a suit, shopping in a fictitious market, etc. Thus, a close relationship is formed between scientific and mathematical domains and disciplines, such as design and entrepreneurship, which is an ideal interaction for promoting STEAM education.

1.3. Learning Based on Traditional Games as an Intercultural Education Channel

Throughout history, play has been a constant presence in all cultures and societies, even the most primitive. We are born, evolve, and live with play [69] (p. 32). From the ethnomathematical standpoint, games have been studied, placing great importance on their cultural representability and their educational applications, as in the case of Aroca studying children's games [70,71] and Palhares examining various educational levels [72–75].

When speaking about traditional games, we are referring to those passed down from generation to generation, being part of the cultural background created by society. These games "constitute authentic cultural heritage. They are an expression of a way of living, acting, entering into contact with the medium and of being able to communicate with others" [76] (p. 30). That is, traditional games, and those that derive from them, fulfil a function of enculturation, conserve and transmit deep popular culture values, favour and facilitate social relationships, and help to conserve the heritage of play. They hold great value in themselves, as they comprise past, present, and future cultural tradition that education should foster [77]. Further, knowledge of other cultures' manifestations of play holds special relevance now because it facilitates a more open attitude from students towards contributions of colleagues from other places of origin [78]. The putting into practice of learning strategies based on traditional games directly contributes to appreciation, understanding, and value on the part of students of different cultural manifestations, a key idea for intercultural education, so closely linked to ethnomathematics [46]. The use of traditional games is ideal for promoting social and intercultural values, as "traditional games reproduce the changing social values in each era given that they are the reflection of the society in which they are immersed" [79] (p. 54). Traditional games emphasize the social component of play, strengthening social skills and cultural values [46].

1.4. Objectives

The educational study and the field study have their own goals but are interrelated.

The educational objectives consist of designing, creating, and implementing activities based on the traditional games selected, constituting a playful microproject, with the ultimate aim of mobilizing mathematical and scientific content in the players.

In the sense of qualitative case studies, hypotheses are proposed here as research questions. Thus our research hypothesis, in the case study that brings together the two educational and field studies, is the following:

"The three traditional games selected have proven mathematical and scientific potential, so they can trigger thoughts and communication that bring together mathematical and scientific content, if they are implemented through an appropriate and efficient didactic design".

This is not properly a "hypothesis" but rather the nucleus of a group of research questions that we have classified as "how", "what", and "how many" concerning the possibility of achieving the educational and research objectives.

How?

How is it possible to demonstrate manifestations of mathematical-scientific content through the creation and implementation of a playful microproject of an ethnomathematical nature? If the games used are able to stimulate mathematical and scientific thinking in the players, in game activities and in the construction of game materials, will we be able to capture meaningful evidence of these activations by observing the players?

If the participants who play interact in pairs, how can we better capture the reasoning of the pairs (on videotape or through observation)? Can this be done by observing their actions, listening to their conversations, asking them questions, answering their questions, or analysing their productions?

What?

What are the elements of mathematical and scientific concepts or procedures that are activated by these games? Are they only conceptualization or also reasoning? Are they related to the curricular goals of primary education? Are they related to each game, or are they common to the entire playful microproject? Can the existence of activation episodes related to the didactic design be affirmed?

How many?

To what extent can we affirm something more than sporadic manifestations? Can we quantify the evidences in the playful microproject? Play activities and making play materials are carried out. Do these two situations have a similar educational potential, proven by quantifying evidence of both types?

2. Materials and Methods

2.1. Educational Methodology. Playful Microproject

Microprojects are interdisciplinary teaching proposals that have the objective of developing skills from a social constructivist perspective, creating activities based on relevant signs from one or more cultures [44,80]. In this work, the signs are traditional games and the activities are focused on play, to which we have designed a "playful microproject". We selected three traditionally inspired board games related to different cultures, taking into account the results of prior anthropological and analytical studies.

The games selected are: The Dog and the Goats (Africa: Canary Islands, Guanche culture), The Towers of the Alhambra (Southern Europe: Spain, Nasrid culture), and Mijnlieff (Northern Europe: Scandinavia, Viking culture).

The game "The Dog and the Goats" is a variation of "Checkers", specific to the Canary Islands, highly established amongst the peoples of a fundamentally pastoral culture [81]. This traditional game was made popular by the "Guanche" people, of Berber origin, who inhabited the Canary Islands before the Spanish conquest in the 15th century [82]. Due to the geological formations of the zone, the islanders made their game boards on flat, smooth stones, which are conserved today (Figure 2). As far as the pieces are concerned, they probably used small stones, seeds, or shells. As regards the rules, these have varied little over the centuries [83]. The game simulates the actions of a dog responsible for helping the shepherd herd the goats, which are feeding freely in the countryside. The goats don't want to enter the pen and, between them, try to stop the dog by grouping around it. The board is made up of 16 (4×4) square or rectangular spaces, whose corners indicate the places to be occupied by the pieces or checkers. There are two types of pieces: 12 white pieces that represent the goats and a single black piece that represents the dog. The objective of the game is to be the first to completely stop the movements of the other player. In other words, the player with the goats will win if he or she manages to immobilise the dog, surrounding it without leaving any spaces. The dog will win if it manages to capture enough goats to avoid being surrounded, jumping over them as in the game "Checkers". The dog always starts the game, moving from the centre vertex towards any other empty neighbouring vertex. It can move forwards or backwards but only one space at a time, except if it can jump over a goat, capturing it, or by doing successive capture jumps in a row. The goats also move one space at a time, always sideways or forwards and, unlike the dog, never backwards. They cannot capture the dog by jumping over it, either.

The game "The Towers of the Alhambra" was created by Francisco López Martin in 2012 [84], set in the emblematic monument of the Andalusian city of Granada: The Alhambra. This genuine fortress of the Nasrid culture was built before the 15th century and includes 35 towers connected by walls, palaces, Arab baths, houses, and gardens, constituting the most important architectural ensemble of Muslim origin in Europe. The game is from the Halma (jump in Greek) family, a concept devised by George Howard Monk in 1883 [85]. In these games, pieces jump over each other to fill the opposite squares. The board, in the form of a checkerboard, is the lid of a box made out of wood and decorated with the traditional ornamental technique known as "marquetry" (Figure 3). This craft is still practiced in Granada and consists of covering a wooden object with small geometric pieces of wood, mother of pearl, or bone such as with a puzzle. There are five pieces for each player. The pieces are small metal sculptures that represent the most striking of the towers of the north wall (bronze) and the south wall (copper) of the Alhambra. The aim of the game is to be the first to move all pieces to the opponent's starting area, so that the opponent wall is "conquered". To do so, it is necessary to move all of the pieces forwards crossways (never diagonally) to adjacent squares. It is possible to make simple or multiple jumps over your own pieces, but not over your opponent's, with the exception of the tallest tower (guide tower) which can jump over the opponent's pieces and is the only one that can move backwards, if no other move is possible.

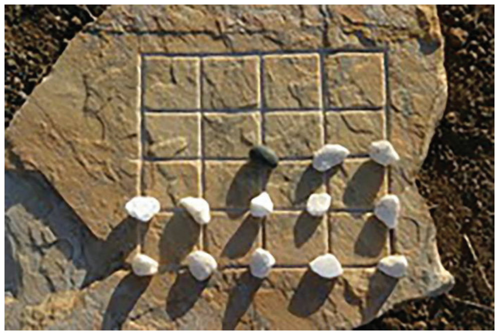


Figure 2. The Dog and the Goats game board with pieces at start position [83].

Figure 3. Board and pieces for the Towers of the Alhambra game, separate and with the initial starting point of the pieces (top). Towers of the Alhambra walls and Granada marquetry objects (bottom). (Source: own creation).

The game "Minjlieff" was created in 2010 by Andy Hopwood, inspired by ancient Talf type games [86]. It was named best abstract game in the 2010 UK Games Expo, the most relevant board games convention in Britain. The launch of the Android version has made it popular, as it can be played online. Talf are old Germanic board games that were played on a square board, simulating two armies, and they imitated the military successes of Viking attacks. They spread wherever the Vikings passed through, including Iceland, Britain, Ireland, and Lapland [87]. The playing of board games fits into the cultural habits of these Nordic groups, given that winter lasted for months and Viking families stayed inside their homes, which were spaces for feasts, conceiving projects, preparing expeditions, and relaxing with board games. Viking culture is hugely attractive in modern society, with its influence being appreciated in music, literature, cinema, and games [88,89].

It is a game for two players; each with different coloured pieces moved one square at a time. There are four signs that characterize the four types of existing pieces and indicate the moves that the opponent can make: towards, away, neighbouring squares, or squares on a common vertex. The board is very original, as it is formed in different ways with four square boards containing 2 × 2 squares (Figure 4). The symbols on the pieces are inspired by runes, signs that made up part of the Viking alphabet and that were typically engraved on stones (Figure 4). Each player has eight pieces, two of each symbol. During play, each piece determines the squares where the opponent can play his or her next piece. If a player is unable to do what the piece indicates, he loses his turn and the opponent puts another one where he wants. The objective of the game is to get the highest possible score, with each point obtained by placing three pieces of the same colour in a row (vertical, horizontal, or diagonal), as in the game "Three in a row". The game ends when no more pieces can be played.

Figure 4. Boards and pieces from the game Minjlieff (top and bottom left). Viking runes and box engraved with the Viking Valknut symbol (bottom right) [90–93].

In order to design the playful microproject activities, special attention has been paid to mathematical and scientific content, but aspects relating to technology, engineering, and art that can be worked with in the games have also been taken into account, exploiting their potential for developing STEAM learning.

2.2. Research Methodology: Case Study

The research methodology followed for the development of the case study is qualitative, descriptive, and interpretative.

The data-gathering techniques employed were direct, observations of the participants were recorded in a field notebook, and the video recording of the microproject was undertaken during the implementation sessions. At all times, a camera was placed on a tripod or held by the researcher, providing video and audio recording of all the evidence, behaviours, and conversations of the students for later analysis. In addition, the researcher in charge of the implementation manually wrote down in a notebook any action that might be relevant to the investigation, resulting in approximately 20 pages of annotations on the sessions conducted. The notes were also analysed.

To interpret the information, we carried out a content analysis [94], with the aim of finding situations that involve mathematical and scientific processes or concepts, activated in the players during the construction and use of the selected games.

Given that we found no precedent techniques contextualized in games, we generated them as part of the study [95], from the results of the analytical study, in which mathematical and scientific content was shown that can be worked on with the traditional games selected. An instrument has been created that combines this mathematical and scientific content [96] associated with the games with the essential components of culture established by Huxley [97]: artefacts, mentifacts, and sociofacts.

Looking in detail at these components for the specific case of a game, we can understand artefacts (material technology of a social group) as being the game materials, that is, board and pieces, mentifacts (abstract elements via which the culture of a group is guided) as the objectives and challenges in the game, and sociofacts (laws that are related with links between individuals and the group [98]), as being the organization rules of the game. The categories are thus obtained a priori, and grouped into three types, for the games implementation analysis (Table 1).

Based on this instrument, a check-list (Appendix A, Table A1) was created and applied to each player, collecting the data of evidence of the categories activated in the players by the game, captured on the recorded video or through observation. The evidences of each category were obtained through this check-list, applying the content analysis and its interpretation to the quotes of the players obtained in the recorded video and to the annotations collected in the field notebook.

Table 1. Data analysis instrument. Categories corresponding to mathematical and scientific content associated with artefacts, mentifacts, and sociofacts of each traditional board game of the playful microproject.

Area	Type	Category	Meaning Contextualized in the Microproject Activities
Mathematics	Artefacts: Game materials	1 Identifying flat shapes and three-dimensional bodies	Distinguishing regular polygons and polyhedrons and assigning them their name
		2 Situating oneself on plane and space	Distinguishing different positions with regards to some references (sides of the playing board and the outside)
		3 Making relationships of order	Sequencing elements spatially or temporally and/or numbering them with ordinals
	Mentifacts: Game objectives and challenges	4 Making classifications	Grouping objects that share one or more properties, separating them from those that lack them, forming subgroups or classes
		5 Making counts	Considering the discreet quantitative aspect of a group, assigning it a natural number (can be game pieces or phases)
		6 Recognizing regularities	Appreciating that patterns are repeated
		7 Giving exact and approximate measurements	Making measurements of magnitude with units already established or conceived by the players
	Sociofacts: Game rules	8 Posing numerical questions	Quantifying aspects that require communication, with the aid of numbers for explaining them
		9 Ascertaining geometric aspects	Posing questions on spatial situations and shapes

Table 1. *Cont.*

Area	Type	Category	Meaning Contextualized in the Microproject Activities
Sciences	Artefacts: Game materials	10 Recognising length	Understanding the linear distance between two points (a dimension of the board)
		11 Recognizing the surface area and volume of a body	Differentiating between two and three dimensions (flat board and pieces, respectively)
		12 Identifying properties of materials	Intuitively understanding approximate values of physical properties of materials (handled for making game board and pieces)
	Mentifacts: Game objectives and challenges	13 Exercising observation	Paying attention (visually and though hearing, without speaking simultaneously)
		14 Proposing hypotheses	Thinking about something that could be done and stating it
		15 Recognizing alternatives	Realizing that you can do something different to that already thought about or done
		16 Demonstrating logical reasoning	Ordering ideas with a cause-effect criterion (coming to relate moves made in the game)
		17 Designing strategies	Thinking about and expressing ways of acting (to win the game)
		18 Experimenting	Making tests before acting or doing various things to see their effects
	Sociofacts: Game rules	19 Evaluating results	Observing something that happened and making an assessment of it
		20 Drawing conclusions	Making inferences or other logical reasoning with a view to guidelines for the future
		21 Predicting	Anticipating something (that could occur in the game)

3. Results

3.1. Results of the Educational Study. Implementation of the Microproject

The playful microproject was implemented, with a total of 32 participants (16 girls and 16 boys) between 7 and 12 years old (Primary Education). Participating players were recruited: 16 in a non-formal education centre in the city of Granada (Spain), 12 in a non-formal education centre in Maracena, a city in the province of Granada, (Spain), and 4 in a group of children of neighbours of one of the researchers, in the city of Granada. The players participating were randomly selected by the heads of each non-formal education centre. The intention was not to have a homogeneous group of students, but to form play groups with students of various types and abilities. After receiving an explanation of the experiment, they volunteered to participate.

Each participant was assigned a code (Appendix A, Table A2).

The implementation was extended over four months, involving three 60-min sessions for each game, organized as follows:

Initial session: The players were grouped into pairs. Each pair was assigned a board game that was the exclusive basis for all activities. The Dog and the Goats was assigned to six pairs (12 participants), the Towers of the Alhambra to another six (12 participants), and Minjlieff to four (eight participants). The traditional board game assigned was presented along with its origin and elements of the culture it is related to, employing different materials (a ppt presentation, drawings, flash cards, and elements that can be handled). A story of our own creation was told, "The tale of Guanche", which involved the story of a shepherd from the Canary Islands passionate about board games whose wish was to create his own game, to which he travelled all around the world discovering different cultures and learning the games they played. After finding discovering the cultural origin of the game, the players dressed up as characters from the culture in the past, they themselves creating the costume with fabric, plastic, and card. To do so they made hats, shields, and other dress elements, taking measurements, drawing, and cutting out. Now in their costumes, the participants assumed the role of locals entrusted with making the game board and pieces. They used recycled materials (boxes, caps, and cartons) and decorated the board to taste with figures from the culture in question (Figure 5).

Figure 5. Construction of game materials for the traditional games selected. Top to bottom: The Dog and the Goats (top), The Towers of the Alhambra (centre), and Mijnlieff (bottom). (Source: Own creation).

Development session: The participants again entered into role play with the constructed material (board and pieces). The rules for their assigned games were explained to them, they familiarized themselves with the games and played them a number of times with help.

Closing session: The participants once again went through the role play process and played the board games in pairs, but this time without help, making their own decisions.

3.2. Research Results. Evidence of Activation of Mathematical and Scientific Content

The details of each player were taken, during interaction with partner or with the researcher, via video recording and field notes.

Even while being aware that a category can be repeated in the same player various times, for the data analysis, if a player stated a category, subsequent posterior evidence of that category was no longer counted. This is done in order to specify the content analysis, reducing it to a maximum of 672 pieces of data (32 players by 21 categories). We understand "evidence of a category" as being an action or verbal expression from the player (comment, response, or question), in which the content associated to the category manifests itself. Examples of evidence of each category for each game are shown in Tables 2–4. Both observations and the transcription of words expressed by the participants are included. The players who showed evidence, the situation in which the category was evidenced, and examples of evidence for each category are tabulated.

Table 2. Codes of the players who showed evidence, evidence situations, and examples of evidences of categories in the game "The dog and the goats".

Category	Player Code/Evidence Situation	Example
1. Identifying flat shapes and three-dimensional bodies	All players show evidence of this category. Making the game board and pieces	It is observed that they all recognise square and rectangle shapes when making the board.
3. Making relationships of order	Players showing evidence of this category: 1A9, 3A9, 4O12, 8A8, 9A9, 10A8, 11A9, 12O12. Making the game board and pieces and Playing	Establish a numerical order when placing the tiles while playing (1,2,3 . . .). A player states the number of steps followed for making the board (12O12)
4. Making classifications	All players show evidence of this category. Making the game board and pieces	When looking for objects to make the pieces, they classify them by colour, creating the white and the black types. A player sort the chips by shape, quantity and colour (1A9)
5. Making counts	Players showing evidence of this category: 1A9, 2A8, 3A9, 4O12, 5O7, 7A7, 8A8, 9A9, 10A8, 11A9, 12O12. Making the game board and pieces	They count the white pieces
6. Recognizing regularities	Players showing evidence of this category: 2A8, 3A9, 4O12, 5O7, 8A8, 9A9, 10A8, 11A9, 12O12. Making the game board and pieces and playing	"I've taken 2 pieces in a row, then one and now another 2" Decorate the box, in which to keep the game, drawing a red flower, followed by a rose, repeating this pattern regularly (4O12).
7. Giving exact and approximate measurements	Players showing evidence of this category: 1A9, 2A8, 3A9, 4O12, 5O7, 6O8, 8A8, 9A9, 10A8, 11A9, 12O12. Making the board.	A player realises that the width of the board corresponds to a succession of various pieces in a row (12O12)
8. Posing numerical questions	Players showing evidence of this category: 1A9, 2A8, 3A9, 4O12, 5O7, 7A7, 8A8, 9A9, 10A8, 11A9, 12O12. Playing	"I've lost 5 pieces, only 3 of the ones I've got left can't be taken by the dog" "You'd take more pieces if you moved 2 rows forward"
10. Recognizing length	All players show evidence of this category Playing	They estimate distances between points during their turns playing
11. Recognizing the surface area and volume of a body	All players show evidence of this category Making the game board and pieces	When constructing the game materials, they distinguish flat figures (board) from three-dimensional bodies (pieces)
12. Identifying properties of materials	Players showing evidence of this category: 2A8, 3A9, 4O12, 9A9, 12O12. Making the game board and pieces	They identify hardness when selecting materials to make the board and pieces
13. Exercising observation	All players except one (4O12) show evidence of this category. Playing	They watch the game closely in order to know what to do while play
14. Proposing hypotheses	Players showing evidence of this category: 1A9, 2A8, 3A9, 10A8, 11A9, 12O12. Playing	"I don't think I'll win because wherever I move he can take me"
15. Recognizing alternatives	Players showing evidence of this category: 1A9, 12O12. Playing	"It's better to keep this piece for the end of the game"
16. Demonstrating logical reasoning	Players showing evidence of this category: 1A9, 2A8, 3A9, 4O12, Playing	"If I move them all together I'll trap it"
17. Designing strategies	Players showing evidence of this category: 9A9, 11A9, 12O12 Playing	"When there are fewer goats left, I'll move the ones in the corners"
18. Experimenting	Players showing evidence of this category: 1A9, 12O12. Playing	Only moves 2 pieces in order to avoid the rest being taken
19. Evaluating results	Players showing evidence of this category: 1A9, 9A9, 11A9, 12O12. Playing	"I played terribly"
20. Drawing conclusions	Players showing evidence of this category: 1A9, 3A9, 9A9, 11A9, 12O12. Playing	"I should have moved another piece that wasn't so close to the dog"

Table 3. Codes of the players who showed evidence, evidence situations, and examples of evidences of categories in the game "The towers of the Alhambra".

Category	Player Code/Evidence Situation	Example
1. Identifying flat shapes and three-dimensional bodies	All players show evidence of this category. Making the game board and pieces	They find the irregular shape of the board strange: "It looks like a rectangle with a square inside" (25O9).
2. Situating oneself on plane and space	Players showing evidence of this category: 13A7, 14O8, 21O9, 23A10. Playing	They begin on the initial starting squares and must move to adjacent squares, not diagonally and they do it correctly
3. Making relationships of order	All players show evidence of this category. Making the game board and pieces and Playing	They order temporally: they indicate that, firstly, you have to make the board and pieces and then, play
4. Making classifications	All players show evidence of this category. Making the game board and pieces and Playing	They classify the pieces by their colour or design
5. Making counts	All players show evidence of this category. Making the game board and pieces	They count how many pieces there are per player and in total. A player counts the tower battlements and how many towers have windows (23A10)
6. Recognizing regularities	All players show evidence of this category. Making the game board and pieces	They establish a pattern of various colours when decorating the board simulating marquetry. When cutting out the battlements, a player indicates that "you have to cut one then not cut the other" (18A11), along with colouring the board with two colours.
7. Giving exact and approximate measurements	A player show evidence of this category: 20O12. Making the game board and pieces	They measure with a ruler. A player calculates the measurements of the board counting the squares (20O12).
8. Posing numerical questions	Players showing evidence of this category: 15O8, 16O9, 17A10, 18A11, 19O11, 20O12, 23A10, 24A9. Playing	"If I move 2 pieces I can block you". "You're on square 4, you can't jump over me on 7"
9. Ascertaining geometric aspects	Players showing evidence of this category: 13A7, 15O8, 16O9, 17A10, 18A11, 19O11, 20O12, 23A10, 24A9. Playing	"If I squash the tower flat, it will look like another square". "I'm moving along the corners of the board, let's see what happens".
10. Recognizing length	All players show evidence of this category. Playing	They estimate distances between points during their turns playing
11. Recognizing the surface area and volume of a body	All players show evidence of this category. Making the game board and pieces	They differentiate flat shapes on a surface of three-dimensional bodies, as the pieces are parallelepiped towers. When they make them they ask questions and speak about it
12. Identifying properties of materials	Players showing evidence of this category: 13A7, 15O8, 16O9, 17A10, 18A11, 19O11, 20O12, 22O9, 23A10, 24A9. Making the game board and pieces	They identify hardness in the board material (box lid) and flexibility in the cartons they cut out to make the pieces
13. Exercising observation	All players show evidence of this category. Playing	They watch the games carefully
14. Proposing hypotheses	Players showing evidence of this category: 14O8, 15O8, 16O9, 17A10, 18A11, 19O11,20O12, 21O9, 22O9, 23A10, 24A9. Playing	"If you pass the middle of the board you've won, because it's easier to move forward". "If I move this piece, you can't move yours and I win on the next move".
15. Recognizing alternatives	Players showing evidence of this category: 18A11, 19O11, 20O12, 21O9 Playing	A player moves the piece he or she has moved incorrectly back, before ending the move (18A11).
16. Demonstrating logical reasoning	Players showing evidence of this category:15O8, 16O9, 17A10, 18A11, 19O11, 20O12, 21O9, 22O9, 23A10, 24A9. Playing	"If I jump over 3, I win". "If I go far enough past you, I win, because you're not going to get me moving one by one". "I move my towers together to make a barrier". "You can't draw"
17. Designing strategies	Players showing evidence of this category: 16O9, 17A10, 18A11, 19O11, 20O12, 21O9, 22O9, 23A10, 24A9. Playing	A player tries to leave a space to take two at a time. Another only moves the forward pieces. Another doesn't start from the initial squares, saying it's to prevent the opponent from getting there. Another player moves the pieces together.
19. Evaluating results	Players showing evidence of this category:7A10, 18A11, 19O11, 20O12, 21O9, 23A10. Playing	"I'm not going to do that anymore". "I'm not going to start anymore". "I should've moved another one". "I don't start first, that's why you always get there before".
20. Drawing conclusions	Players showing evidence of this category: 18A11, 19O11, 20O12, 21O9. Playing	"I'm going to think more in the next one". "I'll move them all together in the next one". "I'm not going to do that anymore". "I'm not going to start anymore".

Table 4. Codes of the players who showed evidence, evidence situations, and examples of evidences of categories in the game "Mijnlieff".

Category	Player Code/Situations	Example
1. Identifying flat shapes and three-dimensional bodies	All players show evidence of this category. Making the game board and pieces and playing.	They recognise circle, rectangle and square in the pieces and board
2. Situating oneself on plane and space	All players show evidence of this category. Playing.	When playing, they understand spatial situations represented by the symbols of the pieces
4. Making classifications	All players show evidence of this category. Making the game board and pieces and playing	They classify the pieces by the different symbols and colours while they make them.
5. Making counts	All players show evidence of this category. Making the game board and pieces	They count the total pieces in the game and the number of different symbols
6. Recognizing regularities	Players showing evidence of this category: 27O11, 28O12, 31A10, 32A9 Making the game board and pieces	They recognise the repetition of patterns in the designs of the pieces and different figures when drawing on the box (one player draws a mandala: 27O11)
7. Giving exact and approximate measurements	All players show evidence of this category. Making the game board and pieces	They measure well with the ruler. Only one player tries another measuring system, placing the pieces in a row to measure the width of the box (28O12)
8. Posing numerical questions	Players showing evidence of this category: 25A11, 26A11, 27O11, 28O12, 30O9, 31A10, 32-A-9. Playing.	One player establishes a number for each piece. Another calculates how many pieces the opponent has left after each move. Another player mentally divides the pieces when distributing them Another adds up the empty spaces to know how many moves he has left and to calculate whether he has enough pieces to win
9. Ascertaining geometric aspects	Players showing evidence of this category: 25A11, 27O11, 28O12, 31A10, 32A9. Playing.	A player creates a mandala combining shapes (27O11). Another uses the pieces as a means for calculating the sizes of the squares that make up the board. Another player relates the shape of the pieces to the squares.
10. Recognizing length	All players show evidence of this category. Making the game board and pieces	They take the measurements of the length of the board and the pieces, comparing them
11. Recognizing the surface area and volume of a body	Players showing evidence of this category: 25A11, 26A11, 27O11, 28O12, 30O9, 31A10, 32-A-9. Making the game board and pieces	They differentiate flat figures (pieces and board) and three-dimensional bodies, with volume (the box)
13. Exercising observation	All students show evidence of this category. Creating the board and pieces and playing	They closely observe the preparation of the materials by the other pairs and then their way of playing.
14. Proposing hypotheses	Player showing evidence of this category: 30O9 Playing.	"I'm going to play this piece, because with this other one X can't move to this square anymore and so I can move there afterwards"
16. Demonstrating logical reasoning	Players showing evidence of this category: 25A11, 26A11, 27O11, 28O12, Playing	"If I place this piece first it's better, because it makes it difficult for X to be able to play hers" "If you put the first piece in the centre it's more difficult for you to win because the other player has more space to put his pieces", "I'm not moving this piece because X only has one left and if I do he beats me", "If I play this piece, X wins because then I'm not going to be able to play the one I have left"
17. Designing strategies	Players showing evidence of this category: 25A11, 26A11, 27O11, 28O12, 30O9, 31A10. Playing	"I've done a good move because X hasn't been able block me", "If I move this piece, it's not good for my opponent". "I'm going to play this piece, because with this other one X can't move to this square anymore and so I can move there afterwards"
18. Experimenting	All students show evidence of this category. Making the board and pieces	They try out materials and designs on the construction of the pieces and the board.

Table 4. *Cont.*

Category	Player Code/Situations	Example
19. Evaluating results	All students show evidence of this category. Making the board and pieces and Playing	"This game really helps you to concentrate", "This game is more complicated than Three in a Row because it has symbols" "At the beginning I found it hard to understand it because I got confused with the symbols, but then it was easy because the picture looked like what you had to do".
20. Drawing conclusions	All students show evidence of this category. Creating the board and pieces and Playing	"I shouldn't have put that piece there", "I have to practice more", "I have good strategies which is why I always win"
21. Predicting	Player showing evidence of this category: 28O12. Playing	"The next game, I'll keep this piece for the end"

With "The dog and the goats" the players show great interest in Guanche culture, they ask why they played with stones, what games they played, and if it still exists. There has been observation of identifications of elemental flat shapes that intervene in the boards: square, rectangle, and triangle. Regarding relationships of order, various players initially placed their pieces following an order they named. Then, when playing, a player moves the pieces following the order of placement and not by game strategy.

They state their game strategies: "If I move along the corners it's more difficult for them to take me", and justify their actions, although they don't constitute a strategy: "I'm slow because if I think, I play better". Experimenting is interpreted by one as cheating when another tries to take two at a time as an experiment. They self-assess, trying to find the reasons for their mistakes, recognizing they have moved without thinking or have made a mistake when moving: "I should have made another more correct move", and conclude with ideas for improving. "Next time I'll wait to take" or "I need to pay more attention". All of the above shows that the participants have played in a conscious manner. A pair wanted to keep playing when time was up and said they would ask for the game when they returned to the playroom, and a player even said he would use it to teach his sister how to count, inventing a didactic application for this game.

In the game "The Towers of the Alhambra" it is observed that, in the construction of the board, the players recognize a rectangle and a square, making reference to its particular shape. In the pieces, which are clearly three-dimensional, they differentiate cube and straight prism. They make mistakes in the placement of the pieces, tending to move them diagonally along the square, as it is the direction that the starting squares go, when the rules require moving to adjacent squares. This makes them focus on directions on the plane that form straight angles. They design strategies trying to gain advantages (one moves all the towers together, another only when the opponent jumps over a piece), although other actions don't make sense (a player retreats from the opposing towers when they get near). Evaluating results at the end of the game is an exercise of reflection that they do quite competently. "I made a mistake because I moved too quickly", "I didn't play well", and from which they draw conclusions: "I'll pay more attention next time", "I need to listen more to your advice" or "I'm not going to start anymore".

It can be seen how the player of this game connected with the monument that it is inspired by. Some indicated that the real towers are harder than these, another made a reference to the towers of the monument as a defensive element, comparing it with its mode of play, another player explained she was Arabic and didn't know the Alhambra and another said: "Thanks to the game, when I go to the Alhambra I'm going to know what the towers are". Some parents present showed an interest in the game, as it was based on the monument in their city, expressing that it was very beautiful. This all favours social awareness and cultural knowledge.

With the game "Mijnlieff" there is a manifestation of the category of making classifications suggested by the pieces, which the players classify with two criteria: colour and symbol shapes. Counting is manifested when counting the total pieces and those for each player, along with the board squares. A participant counts the drawings made on his or her box, recognizing their regularity, and another draws a mandala, explaining what is repeated on it.

Proposing hypotheses is evidenced with expressions such as: "If I play this piece first its better". When playing, statements of logical reasoning occur, such as: "Because it makes it difficult for X to be able to play hers", "If I move this piece, it's not good for my opponent" or "I've done a good move because X hasn't been able block me", even "I can't win because I've got pieces that I can't play left". An alternative referring to a future play is demonstrated: "I'm going to play this piece, because with this other one, X can't move to this square anymore and so I can move there afterwards". Designing strategies is demonstrated with expressions such as: "If I put the pieces on the corners, I save 4 that won't be blocked", which requires thinking about their own move and that of the opponent at the same time. Experimenting has been evidenced in the making of the board and the pieces. The strategy of a player who stated that he was leaving a piece for the end, because this stopped the opponent from winning the game, stood out for its ingenuity. It is the piece that requires another piece to be placed near to it. As the game is at an advanced stage, this piece normally means that opponents cannot place their piece and lose their turn and even the game.

Once the registered evidence was commented on qualitatively, we completed the analysis with a quantitative analysis, providing the frequencies relative to the categories regarding the total number of players who interacted with each game (Table 5). As already indicated, the registry of the evidence has taken place considering each player, who has been counted only once per category manifested. We also provided the relative overall frequencies of the microproject, constituted by the three games as a whole, which have been calculated using the weighted mean of the relative frequencies of the three games.

Table 5. Relative frequencies of each category, evidenced with regards to the total players involved in each game (N) and overall relative frequencies in the microproject (weighted mean of the three games), expressed as a percentage.

Category	Relative Frequency (%)			
	The Dog and the Goats (N = 12)	The Towers of the Alhambra (N = 12)	Mijnlieff (N = 8)	Playful Microproject (N = 32)
1	100	100	100	100
2	0	33	100	37
3	67	100	0	63
4	100	100	100	100
5	88	100	100	96
6	75	100	50	89
7	92	8	100	63
8	50	66	88	88
9	0	74	63	43
10	100	0	100	63
11	100	100	88	97
12	38	84	0	49
13	92	100	100	97
14	50	92	13	56
15	16	33	0	19
16	33	83	50	56
17	25	75	75	56
18	16	0	95	30
19	33	50	100	56
20	42	33	100	53
21	0	0	13	3

The data from the microproject show that 15 categories have been evidenced with a mean frequency of over 50%, with those most manifested by the players being: identifying flat shapes and three-dimensional bodies, making classifications, recognizing the surface area and volume of a body, and exercising observation, with mean frequencies of over 90%, whereas the least evidenced, with 3%, is predicting, as only one player manifested it.

There is evidence of the three types of categories generated (artefacts, mentifacts, and sociofacts). On taking the arithmetic mean of the frequencies of the different categories included within each type we found that, in artefacts, the mean frequency is 65%, in mentifacts, it is greater, 80%, dropping to 48% in sociofacts. This downturn is due to the fact that some categories of this type have been evidenced in few participants. For example, predicting, with 3%, and experimenting, with 30%, as overall frequencies in the microproject. In contrast, there are categories grouped in the mentifacts with the maximum overall frequencies of the microproject.

4. Discussion and Conclusions

The results of this study indicate that it has been possible to design, create, and implement activities based on traditional board games, providing evidence that mathematical and scientific processes or concepts have been activated in the players via interaction with the selected games. It has also been reflected that this is possible by taking these games for the creation of a playful microproject of an ethnomathematical nature, in which such games stimulate mathematical and scientific thinking in the players in two situations: playing situation and situation of construction of materials of the game.

We have confirmed the power of these games for education, generally coinciding with other works [37–51] in the context of mathematical and science processes, concepts, and properties [35,36,52–60]. Likewise, less investigated STEAM aspects are examined, observing that the construction of the game materials also puts these contents into action, coinciding with another study [61].

We have confirmed the power of these games for education, coinciding in general with other works [37–51] within the context of the processes, concepts, and properties mathematics and science [35,36,52–60]. We also examine less investigated matters, observing that the construction of the materials of the games also brings these contents into action, coinciding with another study [61].

Furthermore, these gaming materials are cultural components that are highly valued in ethnomathematics as elements that manifest mathematical thought characteristic of a group. Thus, we verified the importance of artefacts in the knowledge of a culture and in the processes of mathematical and scientific enculturation [18–34].

We investigated games in two situations: from the perspective of their use as a playful activity as well as from the ethnomathematical standpoint of the artisan that makes them [98]. For this, the characteristics of the game must be understood, the materials must be selected and shaped, and the aesthetic form appropriate to the game must be applied. The merging of the two situations in the microproject activated the elements of mathematical, scientific, and STEAM knowledge.

Tables 2–4 show confirmation of the activities in relation to these contents in both situations of the experiment conducted by the players by examples of expressions and deeds faced by the players. The manifestations of certain categories in the situation of playing, and others in the crafts-engineering situation of making, proved more numerous.

It bears noting the categories that were manifested while playing more than while making, or vice versa, and analysing this circumstance qualitatively and quantitatively, as shown in Table 6.

Table 6. Frequencies of each category, evidenced in the situations of playing and/or making, in the three games.

Situations	Playing				Making the Board and Pieces			
				Total Evidence/Category				Total Evidence/Category
Games / Category	The Dog and the Goats	The Towers of the Alhambra	Mijnlieff		The Dog and the Goats	The Towers of the Alhambra	Mijnlieff	
1. Identifying flat shapes and three-dimensional bodies	X		X	2	X	X	X	3
2. Situating oneself on plane and space		X	X	2				0
3. Making relationships of order	X	X		2	X	X		2
4. Making classifications	X			1		X		1
5. Making counts		X	X	2	X	X	X	3
6. Recognizing regularities				0	X	X	X	3
7. Giving exact and approximate measurements	X			1	X	X	X	3
8. Posing numerical questions				0	X	X	X	3
9. Ascertaining geometric aspects	X	X	X	3				0
10. Recognizing length		X	X	2				0
11. Recognizing the surface area and volume of a body	X	X	X	3			X	1
12. Identifying properties of materials				0		X	X	2
13. Exercising observation				0	X	X	X	3
14. Proposing hypotheses				0	X	X		2
15. Recognizing alternatives	X	X		2				0
16. Demonstrating logical reasoning	X	X	X	3			X	1
17. Designing strategies	X	X	X	3				0
18. Experimen-ting	X	X		2				0
19. Evaluating results	X		X	2				0
20. Drawing conclusions	X	X	X	3				0
21. Predicting	X			1			X	1
Total game/evidences	15	13	12		8	9	10	

Quantitatively, 13 categories were found to be evidenced more in playing (62%), 7 (33%) were evidenced more in making, and 3 (14%) were evidenced equally in both situations (Figure 6).

Qualitatively, the categories most evidenced were 1 (Identifying flat shapes and three-dimensional bodies) and 5 (Making counts), which were evidenced in five options of the six possible, and this occurred more in making situations. These were followed the 3 (Making relationships of order) that proved equal in situations, 7 (Giving exact and approximate measurements) more in making, 11 (Recognizing the surface area and volume of a body) more in playing, and 16 (Demonstrating logical reasoning) more in playing. These data reflect consistency among the contents and situations in which they were manifested the most. It should be highlighted that these most evidenced categories form an essential part of the contents and competences of the curriculum of mathematics and sciences of Primary Education in Spain.

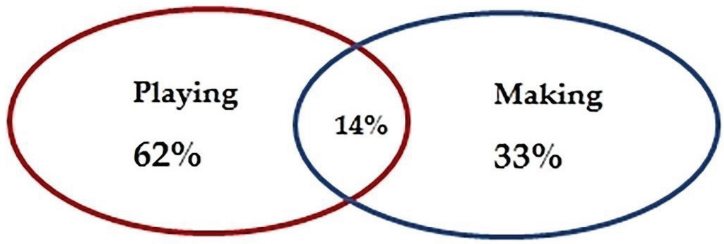


Figure 6. Comparison of the situations in which analytical categories were evidenced.

On the other hand, the playful microproject proved to be a successful didactic proposal in terms of its objectives. Thus, the contribution of this study to the field of Education is important because it shows that the microproject implemented ensures that activities in these games activate an essential part of the core of the curriculum, which should be completed by the student between 7 and 12 years of age.

The three games involved are equivalent in their quantity of manifestations. All the information gathered for each game is another contribution to Cultural Anthropology. This can be used in play centres and workshops for non-formal education, orienting the users on the learning implicit in these games. Therefore, we provide valuable information for cultural knowledge and for mathematical-scientific enculturation within settings of formal, as well as non-formal, education. Overall, a theoretic framework has been developed for ethnomathematics as a research program, and the results can be applied to practical socio-educational efforts with an intercultural focus. The contributions of the present work are presented in Figure 7.

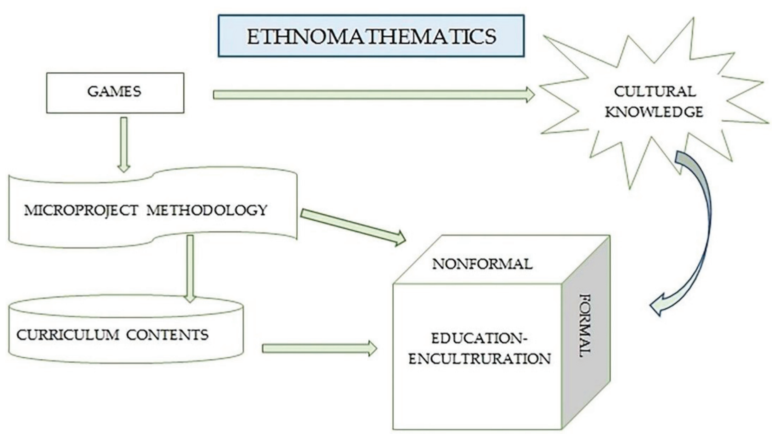


Figure 7. Contributions to cultural and educational fields with an ethnomathematical focus.

The limitations of the present study involve the setting and the interactions with the players since the making and use of these games could not be experienced in student surroundings of formal education due to the restrictions of the use of materials and relations with other people from outside the schools, due to the existing COVID-19 pandemic. Therefore, interviews could not be made with players after the implementation of the microproject. Both aspects, i.e., experimentation in a broader sample that includes schools (formal education) and interviews with the players included in the microproject to delve into the cognitive aspects, constitute perspectives for future investigation in this line.

Overall, the three traditional selected games have favoured the activation of mathematical and scientific content in a STEAM context, being appropriate as cultural signs for creating a playful microproject. When making their gaming materials and playing with them, 21 categories established a priori have been revealed. These categories were related to the concepts of artefacts, mentifacts, and sociofacts that characterize culture [97], forming three typologies. Evidence of these three types of categories was found, by means of a checklist [99] developed and applied to the players, with the mentifacts being the most evidenced.

They are important in mathematical and scientific learning; content related to the nature of scientific and mathematical thinking, such as the formulation of hypotheses, recognition of regularities, the establishment of relationships of order, strategy design, logical reasoning, and the evaluation of situations, with categories evidenced with mean percentages exceeding 56% of players.

In the playful setting and STEAM context in which the activities of the microproject have been developed, other mathematical content has been activated, such as: counting and putting forward numerical questions particular to arithmetic (mean frequencies over 85%), together with identifying the flat shapes and three-dimensional bodies particular to geometry (mean frequency of 100%). Scientific content has also been activated, such as: recognizing length, surface, and volume of a body (mean frequencies higher than 63%), giving exact and approximate measurements (mean frequencies over 56%) and identifying properties of materials (mean frequency of 49%). This all stimulates us to propose this games-based microproject for learning mathematics and science in a STEAM context, for non-formal and formal settings alike.

In addition, the implementation of the playful microproject has meant that attention has been drawn to traditional games of diverse origins, favouring respect and understanding towards all cultures, thus promoting key values of intercultural education.

Author Contributions: Conceptualization, A.F.-O. and M.L.O.; Data curation, M.J.E.-G. and M.L.O.; Formal analysis, A.F.-O., M.J.E.-G. and M.L.O.; Methodology, A.F.-O. and M.L.O.; Resources, A.F.-O. and M.L.O.; Supervision, A.F.-O. and M.L.O.; Visualization, A.F.-O.; Writing—original draft, A.F.-O., M.J.E.-G. and M.L.O.; Writing—review & editing, A.F.-O. and M.L.O. Project administration, A.F.-O. Funding acquisition, A.F.-O. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by University of Granada, grant numbers PPJI2018-06 and PID 18-363.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by Ethics Committee of University of Granada (protocol code 1704/CEIH/2020 and date of approval 30 September 2020).

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. The data are not publicly available due to privacy.

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

Appendix A

Table A1. Check-list to collect evidences of the categories activated in each player by the game.

Player Code (N°, Boy: O/Girl: A, Years. Example: 1A9 = 1°, Girl, 9 Year Old) **Category (from 1 to 21)**	Evidence Captured with Recorded Video. Quote Player Phrases or Gestures (Sessions 1–3)	Evidence Gathered by Direct Observation and Written in the Field Notebook (Sessions 1–3)	Situation: Playing (put X if applicable)	Situation: Making the Board and the Pieces (put X if applicable)

Table A2. Codification table of the players.

Game Pairs	Player Code	Gaming Place	Game Played
Pair 1	1-A-9	ALFA play centre	The dog and the goats
	2-A-8	ALFA play centre	
Pair 2	3-O-9	ALFA play centre	
	4-O-12	ALFA play centre	
Pair 3	5-O-7	Neighbourhood community room	
	6-O-8	Neighbourhood community room	
Pair 4	7-A-7	Neighbourhood community room	
	8-A-8	Neighbourhood community room	
Pair 5	9-A-8	Maracena play centre	
	10-A-8	Maracena play centre	
Pair 6	11-A-8	Maracena play centre	
	12-O-7	Maracena play centre	
Pair 7	13-A-7	ALFA play centre	Torres de la Alhambra
	14-O-8	ALFA play centre	
Pair 8	15-O-8	ALFA play centre	
	16-O-9	ALFA play centre	
Pair 9	17-A-10	ALFA play centre	
	18-A-11	ALFA play centre	
Pair 10	19-O-11	ALFA play centre	
	20-O-12	ALFA play centre	
Pair 11	21-O-9	Maracena play centre	
	22-O-9	Maracena play centre	
Pair 12	23-A-10	Maracena play centre	
	24-A-9	Maracena play centre	
Pair 13	25-A-11	ALFA play centre	Mijnlieff
	26-A-11	ALFA play centre	
Pair 14	27-O-11	ALFA play centre	
	28-O-12	ALFA play centre	
Pair 15	29-O-9	Maracena play centre	
	30-O-9	Maracena play centre	
Pair 16	31-A-10	Maracena play centre	
	32-A-9	Maracena play centre	

References

1. Huizinga, J. *Homo Ludens, Ils 86*, 1st ed.; Routledge: London, UK, 2013. [CrossRef]
2. Huizinga, J. De lo lúdico y lo serio. In *Acerca de los Límites Entre lo Lúdico y lo Serio en la Cultura*; Aullón de Haro, P., Huizinga, J., Eds.; Casimiro Libros: Madrid, Spain, 2014; pp. 19–60.
3. Benalcázar, M.M.B.; Guamán, J.L.U.; Torres-Toukoumidis, A. Análisis descriptivo del juego como herramienta para aprender sobre el patrimonio cultural: Estudio de caso. *Estud. Pedagógicos* **2020**, *3*, 33–44. [CrossRef]
4. Cornellà, P.; Estebanell, M.; Brusi, D. Gamificación y aprendizaje basado en juegos. *Enseñanza Cienc. Tierra* **2020**, *28*, 5–19.
5. Latorre, A.J. *Juego y Educación: Aplicación de la Construcción y Uso de Juegos Educativos a los Procesos de Enseñanza y Aprendizaje*; Dirección General de Promoción Educativa: Madrid, Spain, 2003.
6. Glenberg, A.M.; Robertson, D.A. Indexical understanding of instructions. *Discourse Process.* **1999**, *1*, 1–26. [CrossRef]
7. Garaigordobil, M. *Juego Cooperativo y Socialización en el Aula*, 1st ed.; Seco-Olea: Madrid, Spain, 1992.
8. Piaget, J. *La Formación del Símbolo en el Niño: Imitación, Juego y Sueño. Imagen y Representación*; Fondo de Cultura Económica: Madrid, Spain, 2019.
9. Vigotsky, L. Interacción entre enseñanza y desarrollo. *Sel. Lect. Psicol. Edades* **1988**, *3*, 37–45.
10. Morris, B.; Croker, S.; Zimmerman, C.; Gill, D.; Romig, C. Gaming science: The "Gamification" of scientific thinking. *Front. Psychol.* **2013**, *4*, 607. [CrossRef] [PubMed]
11. Bergen, D. Play as the Learning Medium for Future Scientists, Mathematicians, and Engineers. *Am. J. Play* **2009**, *4*, 413–428.
12. Espigares-Gámez, M.J.; Fernández-Oliveras, A.; Oliveras, M.L. Compilation of traditional games played in Jamaica: An ethnomathematical study for steam education. In Proceedings of the ICERI 2019 Conference, Sevilla, España, 11–13 November 2019; pp. 9643–9649.

13. Espigares-Gámez, M.J.; Fernández-Oliveras, A.; Oliveras M., L. Games as STEAM learning enhancers. Application of traditional Jamaican games in Early Childhood and Primary Intercultural Education. *Acta Sci.* **2020**, *4*, 28–50. [CrossRef]
14. Espigares-Gámez, M.J.; Fernández-Oliveras, A.; Oliveras, M.L. Instrumento para evaluar competencias matemáticas y científicas del alumnado que inicia Educación Primaria, mediante juegos. *Rev. Paradig.* **2020**, *41*, 326–359. [CrossRef]
15. Bishop, A. El papel de los juegos en la educación matemática. *UNO Rev. Didact. Mat.* **1998**, *8*, 9–19.
16. Espigares-Gámez, M.J.; Fernández-Oliveras, A.; Oliveras, M.L. Anthropological and analytical studies for the design of a playful microproject devoted to mathematics and science education. In Proceedings of the INTED2021 Proceedings, Online, 8–9 March 2021; pp. 1876–1881.
17. Oliveras, M.L. El pensamiento creativo, la crítica y la comunicación en ICEm5. *Rev. Latinoam. de Etnomatemática Perspect. Sociocult. de la Educ. Matemática* **2015**, *2*, 4–10.
18. D'Ambrosio, U.; Rosa, M. Um diálogo com Ubiratan D'Ambrosio: Uma conversa brasileira sobre etnomatemática. *Rev. Latinoam. de Etnomatemática Perspect. Sociocult. de la Educ. Matemática* **2008**, *2*, 88–110.
19. D'Ambrosio, U. The program Ethnomathematics: Cognitive, anthropological, historic and socio-cultural bases. *PNA* **2018**, *12*, 229–247.
20. Oliveras, M.L. *Matemáticas en la Sociedad*; Fuentes, J., Oliveras, M.L., Eds.; Repro Digital: Granada, Spain, 2000; ISBN 84-6070657-5.
21. Oliveras, M.L. Etnomathematics and Etnodidactics. In Proceedings of the First International Conference on Ethnomathematics (ICEM 1), Granada, Spain, 2–5 September 1998; Fuentes, J., Ed.; University of Granada: Granada, Spain, 1998; pp. 91–106.
22. D'Ambrosio, U. Ethnomathematics and its place in the history and pedagogy of mathematics. *Learn. Math.* **1985**, *5*, 44–48.
23. Bishop, A. *Mathematical Enculturation. A Cultural Perspective on Mathematics Education*; Springer Science & Business Media: Berlin/Alemania, Germany, 1991.
24. Gerdes, P. Ethnomathematics and Mathematics Education. In *International Handbook of Mathematics Education*; Bishop, A.E., Clements, K., Keitel, C., Kilpatrick, J., Laborde, C., Eds.; Kluwer Academic Publishers: Dordrecht, Germany, 1996; pp. 909–943.
25. D'Ambrosio, U. Literacy, Matheracy, and Technoracy: A Trivium for Today. *Math. Think. Learn.* **1999**, *1*, 131–153. [CrossRef]
26. Zaslavsky, C. *Africa Counts: Number and Pattern in African Cultures*; Lawrence Hill Books: Chicago, IL, USA, 1999.
27. Ascher, M. *Ethnomathematics. A Multicultural view of Mathematical Ideas*; Brooks/Cole Co.: Pacific Grove, CA, USA, 1991.
28. Powell, A.B.; Frankenstein, M. (Eds.) *Ethnomathematics: Challenging Eurocentrism in Mathematics Education*; State University of New York Press: Albany, NY, USA, 1997; p. 7.
29. Knijnik, G.; Wanderer, F.; Giongo, I.; Duarte, C. *Etnomatemática em Movi-Mento*; Autentica: Belo Horizonte, Brazil, 2012.
30. Barton, B. Mathematics, Education, and Culture: A Contemporary Moral Imperative. In Proceedings of the 13th International Congress on Mathematical Education, Hamburg, Germany, 24–31 July 2016; Springer: Berlin/Heidelberg, Germany, 2017; pp. 35–43. [CrossRef]
31. Blanco-Álvarez, H.; Higuita, C.; Oliveras, M.L. Una mirada a la Etnomatemática y la Educación Matemática en Colombia: Caminos recorridos. *Rev. Latinoam. de Etnomatemática Perspect. Sociocult. de la Educ. Matemática* **2014**, *7*, 245–269.
32. Fuentes Leal, C. Algunos enfoques de investigación en Etnomatemática. *Rev. Latinoam. de Etnomatemática Perspect. Sociocult. de la Educ. Matemática* **2014**, *7*, 155–170.
33. D'Ambrosio, U. *Etnomatemática. Entre las Tradiciones y la Modernidad*; Limusa: México City, México, 2008.
34. Rosa, M.; Orey, D. Etnomatemáticas: Los aspectos culturales de las matemáticas. *Rev. Latinoam. de Etnomatemática Perspect. Sociocult. de la Educ. Matemática Perspect. Sociocult. Educ. Mat.* **2011**, *4*, 32–54.
35. Alsina i Pastells, À.; Planas Raig, N. *Matemática Inclusiva: Propuestas Para una Educación Matemática Accesible*; M Narcea: Madrid, Spain, 2008.
36. De Guzmán, M. Enseñanza de las ciencias y la matemática. *Rev. Iberoam. Educ.* **2007**, *43*, 19–58.
37. Espigares-Gámez, M.-J.; Fernández-Oliveras, A.; Oliveras, M.-L. Análisis de juegos. Catálogo de juegos tradicionales para trabajar áreas científicas y matemáticas. In *Innovación Educativa en la Sociedad Digital*; Sola, T., García, M., Fuentes, A., Rodríguez-García, A.M., López, J., Eds.; Dykinson: Madrid, España, 2019; pp. 2186–2200.
38. Fernández-Oliveras, A.; Espigares-Gámez, M.J.; Oliveras, M.L. Teorizaciones para la tipificación de juegos con potencial educativo STEAM. In *Innovación Educativa en la Sociedad Digital*; Sola, T., García, M., Fuentes, A., Rodríguez-García, A.M., López, J., Eds.; Dykinson: Madrid, España, 2019; pp. 1645–1658.
39. Chawla, L. Benefits of Nature Contact for Children. *J. Plan. Lit.* **2015**, *4*, 433–452. [CrossRef]
40. Yakman, G.; Lee, H. Exploring the exemplary STEAM education in the US as a practical educational framework for Korea. *J. Korean Assoc. Sci. Educ.* **2012**, *32*, 1072–1086. [CrossRef]
41. Cilleruelo, L.; Zubiaga, A. Una aproximación a la Educación STEAM. Prácticas educativas en la encrucijada arte, ciencia y tecnología. *Actas Jorn. Psicodidáctica* **2014**, *4*, 1–18.
42. Sullivan, A.; Strawhacker, A.; Umaschi Bers, M. Dancing, Drawing, and Dramatic Robots: Integrating Robotics and the Arts to Teach Foundational STEAM Concepts to Young Children. In *Robotics in STEM Education: Redesigning the Learning Experience*; Khine: London, UK, 2017; pp. 231–260. [CrossRef]
43. Oliveras, M.L. *Etnomatemáticas Formación de Profesores e Innovación Curricular*; Comares: Granada, Spain, 1996.
44. Fernández-Oliveras, A.; Oliveras, M.L. Formación de maestros y Microproyectos curriculares. *Rev. Latinoam. de Etnomatemática Perspect. Sociocult. de la Educ. Matemática* **2015**, *2*, 472–495.

45. Park, N.; Ko, Y. Computer education's teaching learning methods using educational programming language based on STEAM education. In Proceedings of the 9th International Conference on Network and Parallel Computing (NPC), Gwangju, Korea, 6–8 September 2012; Park, J.J., Zomaya, A.A., Yeo, S.-S., Sahni, S.S., Eds.; Springer: Berlin/Heidelberg, Germany, 2012; pp. 320–327.
46. Oliveras, M.L. Etnomatemáticas. De la multiculturalidad al mestizaje. In *Matemáticas e Interculturalidad*, 2nd ed.; Goñi, J., Ed.; Graó: Barcelona, Spain, 2006; pp. 117–149.
47. Craft, A. *Creativity in the School*; Beyond Current Horizons Project: London: UK, 2008.
48. Ananiadou, K.; Claro, M. *21st Century Skills and Competences for New Millennium Learners in OECD Countries*; OECD Publishing: Paris, France, 2009.
49. Rotherham, A.J.; Willingham, D.T. 21st century skills, not new, but worthy challenge. *Am. Educ.* **2010**, *1*, 17–20.
50. National Advisory Committee on Creative, Cultural Education. *All our Futures: Creativity, Culture & Education*; Department for Education and Employment: London, UK, 1999. Available online: http://sirkenrobinson.com/pdf/allourfutures.pdf (accessed on 11 July 2021).
51. Pombo, L.; Marques, M.M. The potential educational value of mobile augmented reality games: The case of EduPARK app. *Educ. Sci.* **2020**, *10*, 287. [CrossRef]
52. Yuste, F.C.; Piquet, J.D. Juegos manipulativos en la enseñanza de las matemáticas. *UNO Rev. Didáctica Mat.* **1996**, *7*, 71–80.
53. Deulofeu, J. *Una Recreación Matemática: Historias, en el Alumnado de Secundaria*; Planeta: Barcelona, Spain, 2001.
54. Zhao, Z.; Linaza, J.L. La importancia de los videojuegos en el aprendizaje y el desarrollo de niños de temprana edad. *Electron. J. Res. Educ. Psychol.* **2015**, *2*, 301–318. [CrossRef]
55. Evans, M.A. Mobility, Games and Education. In *Handbook of Research on Effective Electronic Gaming in Education*; Hershley: New York, NY, USA, 2009; pp. 96–110.
56. Tokac, U.; Novak, E.; Thompson, C. Effects of Game-Based Learning on Students' Mathematics. Achievement: A Meta-Analysis. Representing Florida State University 2015. In Proceedings of the Statewide Graduate Student Research Symposium, Orlando, FL, USA, 24 April 2015.
57. National Mathematics Advisory Panel. *Foundations for Success: The Final Report of the National Mathematics Advisory Panel*; U.S. Department of Education: Washington, DC, USA, 2008.
58. Wilcox, S. Praxis Games. A Design Philosophy for Mobilizing Knowledge through Play. *Am. J. Play* **2019**, *11*, 156–182.
59. González González, C.S. Estrategias para trabajar la creatividad en la Educación Superior: Pensamiento de diseño, aprendizaje basado en juegos y en proyectos. *Rev. Educ. Distancia* **2015**, *1*, 40.
60. Méndez-Giménez, A.; Fernández-Río, J. Efectos del uso de materiales autoconstruidos sobre la satisfacción, el aprendizaje, las actitudes y las expectativas del alumnado de magisterio de la asignatura Juegos Tradicionales. In Proceedings of the International Congress AIESEP, A Coruña, Spain, 26–29 October 2010; pp. 26–36.
61. LLeixà, T. Educación física y competencias básicas. Contribución del área a la adquisición de las competencias básicas del currículo. *Tándem Didact. Educ. Física* **2007**, *23*, 31–37.
62. Perrotta, C.; Featherstone, G.; Aston, H.; Houghton, E. *Game-Based Learning: Latest Evidence and Future Directions*; National Foundation for Educational Research: London, UK, 2013.
63. Kenny, R.; McDaniel, R. The role teachers' expectations and value assessments of video games play in their adopting and integrating them into their classrooms. *Br. J. Educ. Technol.* **2011**, *2*, 197–213. [CrossRef]
64. Kirriemuir, J.; McFarlane, A. *Literature Review in Games and Learning*; University of Bristol: Bristol, UK, 2004. Available online: http://www.futurelab.org.uk/download/pdfs/research/lit_reviews/Games_Review1 (accessed on 11 July 2021).
65. Mitchell, A.; Savill-Smith, C. *The Use of Computer and Video Games for Learning. A Review of the Literature*; Learning and Skills Development Agency: London, UK, 2004. Available online: http://www.lsda.org.uk/files/PDF/1529.pdf (accessed on 11 July 2021).
66. Higgins, E.; Grant, H.; Shah, J. Self-Regulation and quality of life: Emotional and nonemotional life experiences. In *Well-Being: The Foundations of Hedonic Psychology*; Kahneman, D., Diener, E., Schwarz, N., Eds.; Russell Sage Fundation: New York, NY, USA, 1999; pp. 244–266.
67. Bonk, C.J.; Dennen, V.P. *Massive Multiplayer Online Gaming: A Research Framework for Military Training and Education*; University at Bloomington: Bloomington, IN, USA, 2005.
68. López-Fernández, L. Aprendizaje Basado en Metodologías que Apoyan la Lúdica y el Juego. Master's Thesis, Universidad de Almería, Almería, Spain, 2013.
69. Paredes, J. *Juego, Luego Soy. Teoría de la Actividad Lúdica*; Wanceulen: Sevilla, Spain, 2003.
70. Aroca, A. Universidad del Atlántico. Producciones Audiovisuales Etnomatematica (4 de Junio de 2021). Matemáticas Detrás de mi Casa. Serie Matemáticas en Juegos de Niñas y/o Niños. Vídeo 12. [Archivo de Vídeo]. Available online: https://www.youtube.com/watch?v=205hahmB38s (accessed on 11 July 2021).
71. Aroca, A. Universidad del Atlántico. Producciones Audiovisuales Etnomatemática (19 de Junio de 2021). Matemáticas en la Gallina Pijabá. Serie Matemáticas en Juegos de Niñas y/o Niños. Vídeo 13. [Archivo de Vídeo]. Available online: https://www.youtube.com/watch?v=HTMkDKphWRU (accessed on 11 July 2021).
72. Ferreira, D.; Palhares, P.; Silva, J.N. A perspective on games and patterns. In *New Pedagogical Approaches in Game Enhanced Learning: Curriculum Integration*; IGI Global: Hershey, PA, USA, 2013; pp. 60–80.

73. Ferreira, D.; Palhares, P.; Silva, J.N. Mathematical games played by elementary school students. *GRIM Quad. Ric. Didatt. Math.* **2012**, *22*, 95–98.
74. Ferreira, D.; Palhares, P.; Silva, J.N. Padrões e jogos matemáticos. *Rev. Eletron. Educ. Mat.* **2008**, *3*, 30–40.
75. Palhares, P. *O Jogo e o Ensino/Aprendizagem da Matemática*; Instituto Politécnico de Viana do Castelo, Escola Superior de Educação: Viana do Castelo, Portugal, 2004.
76. Yagüe, V. *Juegos de Ayer y de Siempre*; Madrid SL: Madrid, Spain, 2002.
77. Trigueros, C. Nuevos Significados del Juego Tradicional en el Desarrollo Curricular de la Educación Física en Centros de Educación Primaria de Granada. Ph.D. Thesis, Universidad de Granada, Granada, Spain, 12 January 2020.
78. Estrada, J.A.C.; González-Mesa, C.G.; Méndez-Giménez, A.; Fernández-Río, J. Achievement goals, social goals, and motivational regulations in physical education settings. *Psicothema* **2011**, *1*, 51–57.
79. Gros, B. La dimensión socioeducativa de los videojuegos. *Edutec Rev. Electron. Tecnol. Educ.* **2000**, *23*, 1–11. Available online: http://edutec.rediris.es/Revelec2/Revelec12/gros.pdf (accessed on 11 July 2021).
80. Oliveras, M.L. Microproyectos Para La Educación Intercultural En Europa. *UNO Rev. Didact. Mat.* **2005**, *38*, 70–81.
81. Baute, J. Juego de la dama. *Rev. Bien Me Sabe* **2008**, *892*, 4–8. Available online: https://www.bienmesabe.org/noticia/buscar?q=833 (accessed on 11 July 2021).
82. Molina, J. *Conocimientos Científicos y Técnicos de los Guanches*; InfoNorte Digital: Galdar, Spain, 2003.
83. Bien Me Sabe. Available online: https://www.bienmesabe.org/noticia/2008/Octubre/juego-de-la-dama (accessed on 11 July 2021).
84. Asociación Cultural Jugamos Todos. Las Torres de la Alhambra. Available online: https://www.jugamostodos.org/index.php/noticias-en-espana/en-produccion/3196-las-torres-de-la-ahambra (accessed on 11 July 2021).
85. Gutiérrez Perera, C.S. *Programación Didáctica de la Asignatura de 4° de ESO Trabajo Monográfico de Investigación: "Juegos de Mesa del Mundo y Etnomatemáticas"*; University of Valencia: Valencia, Spain, 2014.
86. Hoopwood Games. Available online: https://www.hopwoodgames.com/shop-1/mijnlieff (accessed on 11 July 2021).
87. Attia, P. *La Muy, Muy Larga Pero Imprescindible Historia de los Juegos de Mesa*; Magnet: Madrid, Spain, 2016. Available online: https://magnet.xataka.com/en-diez-minutos/la-larga-historia-de-los-juegos-de-mesa (accessed on 11 July 2021).
88. Cohat, I. *Los Vikingos, Reyes de los Mares*; Aguilar: Madrid, Spain, 1989.
89. Velasco, M. *Breve Historia de los Vikingos.*; Nowtilus: Madrid, Spain, 2009.
90. Boardspace. Available online: https://www.boardspace.net/english/about_mijnlieff.html (accessed on 11 July 2021).
91. Uplayit. Available online: https://www.uplay.it/gioco-da-tavolo-Mijnlieff.html (accessed on 11 July 2021).
92. The Abstract Rat. Available online: http://www.theabstractrat.com/reviews/mijnlieff (accessed on 11 July 2021).
93. El Rayón Artesanías. Available online: https://elrayon.es/oraculos/24-runas-vikingas-futhark.html (accessed on 11 July 2021).
94. Berelson, B. *Content Analysis in Communication Researches. Foundations of Communications Research*; Glencoe: New York, NY, USA, 1952.
95. Bardin, L. *El Análisis de Contenido*; Akal: Madrid, Spain, 1986.
96. D'Ambrosio, U. La integración de la matemática con las ciencias. *Mat. Rev. Digit. Divulg. Mat. Real Soc. Mat. Esp.* **2005**, *1*. Available online: http://www.matematicalia.net/index.php?option=com_content&task=view&id=27&Itemid=27 (accessed on 11 July 2021).
97. Huxley, J.S. Guest editorial: Evolution cultural and biological. In *Yearbook of Anthropology*; The University of Chicago Press: Chicago, IL, USA, 1955; pp. 2–25.
98. White, R.T. *Learning Science*; Basil Blackwell: Oxford, UK, 1988.
99. Cano, E. The rubrics as an assessment tool of competency in higher education: Use or abuse? *Profesorado* **2015**, *19*, 265–280. Available online: https://recyt.fecyt.es/index.php/profesorado/article/view/41533 (accessed on 11 July 2021).

education sciences

MDPI

Article

Educational Hall Escape: Increasing Motivation and Raising Emotions in Higher Education Students

Almudena Macías-Guillén [1], Raquel Montes Díez [2], Lucía Serrano-Luján [2] and Oriol Borrás-Gené [2,]*

[1] Faculty of Law and Social Sciences, University Rey Juan Carlos, 28933 Madrid, Spain; almudena.macias@urjc.es

[2] Technical School of Computer Engineering, University Rey Juan Carlos, 28933 Madrid, Spain; raquel.montes@urjc.es (R.M.D.); lucia.serrano@urjc.es (L.S.-L.)

* Correspondence: oriol.borras@urjc.es

Abstract: Educational Escape Room is an innovative method used in classrooms to motivate students. This article describes a version of Educational Escape Room applied to undergraduate students. Specifically, this work presents an adaptation of the method called Educational Hall Escape, characterized by the resolution of challenges in a game-adapted room in which several student groups compete to finish the activity in the least amount of time. To date, the Educational Hall Escape method applied to the field of business economy has not been reported in the literature. The objective of the study is to analyze the influence of the Educational Hall Escape method on the learning processes and emotions of students during the activity and its impact on their motivation and the reinforcement their competences and knowledge. An experiment was designed in which the class was divided into a control group and an experimental group. To measure the impact of the experience in the students, two tools were used: an exam and the Gamefulquest survey. Despite the fact that the results obtained show that the students perceived the experience as a game, it improved their motivation and increased their proclivity to have an emotional bond with the subject, the academic results remained steady.

Keywords: gamification; serious games; game-based learning; escape room; motivation; higher education

Citation: Macías-Guillén, A.; Díez, R.M.; Serrano-Luján, L.; Borrás-Gené, O. Educational Hall Escape: Increasing Motivation and Raising Emotions in Higher Education Students. *Educ. Sci.* **2021**, *11*, 527. https://doi.org/10.3390/educsci11090527

Academic Editors: José Carlos Piñero Charlo, María Teresa Costado Dios, Enrique Carmona Medeiro and Fernando Lloret

Received: 9 July 2021
Accepted: 7 September 2021
Published: 9 September 2021

1. Introduction

Educational simulation based on games, objects, or dynamic processes, is a teaching tool that could enhance the understanding of the subject content since it opens up the comprehension of ideas and abstract concepts. Educative simulation is ideal for manipulating and modifying the learning process, depending on the educational needs of each moment, and it is useful in transporting us to a place and time that would be impossible to reach as a real experience in the classroom [1].

The use of innovative teaching methodologies based on games is increasingly employed in the classroom. Game-Based Learning (GBL) is a methodology centered on the educational potential of the games as an enabling tool to learn in a motivational, creative and participative form [2]. Escape Room is a learning strategy that is increasingly used, which promotes the motivation and commitment of the students to the learning process [3].

The present study aims to examine the emotions produced by an Educational Escape Room (EER) experience. The emotions in the activity deal with an early feeling of stress, followed by satisfaction as the students solve the challenges. The evolution of the feelings is related to the self-confidence students experience during the activities regardless of the results of the game (win/loss).

It specifically applies an EER variation, named Educational Hall Escape (EHE), consisting of the performance of the game by several student teams simultaneously in the same educational space (classroom) and in a competitive environment. EHE is a tool that motivates, enhances and strengthens skills and knowledge dealing with the subject's topic, i.e., introduction to business.

Our goal consists of analyzing the appropriateness of a ludic activity and its acceptance by the students enrolled in a Marketing Degree. The principal aspects to consider when reproducing this model in different educational environments will be identified and detailed.

In order to achieve this objective, an educational research experiment was designed. The tool applied is an EHE. The class was split into control and experimental groups to assess the teaching impact. This experience is based on four research hypotheses:

Hypothesis 1 (H1). *Students enrolled in the EHE exhibit better academic results than students who were not.*

Hypothesis 2 (H2). *Students enrolled in the EHE felt the activity as a complete game experience in all its dimensions.*

Hypothesis 3 (H3). *Students enrolled in the EHE showed higher signs of motivation than those who were not.*

Hypothesis 4 (H4). *Students enrolled in the EHE felt more emotions during the activity than those who did not perform it.*

Throughout this article, a literature review on Educational Escape Rooms is conducted, in Section 2, to obtain a brief state of the art summary of its application. In Section 3, Methodology, presents the development of the experience and the obtained EHE methodology. Finally, the results are discussed and a conclusion from the experience is displayed.

2. Theoretical Background

2.1. "Serious Games" and "Gamification"

The use of game elements in education has been widely utilized since the beginning of the education system, mainly at preschool and primary school levels. Play in school has been taken on the normal characteristics and expectation of formal schooling [4]. It was a question of time for games to start being applied to higher education.

Concerning the subject the present study deals with, game theory found a natural place in economics [5]. The first application of gaming to economics dates back to Cournot (1838) [6], and several studies describing its application have been reported since then. This natural link between the game and the economic field results in an attractive arena for teaching methods. As McDonald expounds in his book "The Game of Business", business theory and its management can be understood as an oligopolistic game, where the player must face real world situations [7]. Thus, game-based learning techniques are applied worldwide to encourage students, irrespective of the level of education.

The methodology consisting of the use of the fundamentals and technology of games to understand real-life complexity has received several names, such as "simulation games", "serious games", "applied games", "persuasive games", and "gamification" [8]. The terms most commonly found in the literature when reporting an EER, as in the present study, are "serious games" and "gamification". Here, we underline the differences between them.

"Serious games" are based on complete games, with the entertainment component in the background and education-centered [9,10]. They have an explicit educational purpose and possess all game elements, such as specific rules, boundaries, procedures, players, objectives, and they also look like games despite their pedagogical aim [11,12]. "Simulations" are also considered "serious games", since they allow students to be introduced into different learning situations, complementing formal learning [10,13,14]. "Serious games" have enjoyment (or the game itself) as an intrinsic value, and an extrinsic value, consisting of the pursued goal which is the sake of beneficial consequences different from the game's sake [8], that would be the learning process in the context of this study. Mayer also underlines the connection between game, emotions and learning in "serious games".

As a "serious game", "gamification" is one of the most referenced methods to enhance the motivation in the classrooms during recent decades, and it is defined as "The process of game-thinking and game mechanics to engage users and solve problems" [15]. Marczewski proposes different approaches to the application of games or their techniques within the so-called "game thinking", with a final purpose other than entertainment, "gamification" and "serious games" [14].

Although the origin of the term "gamification" is unknown, the first use of the term was in 2008 in the digital media industry [16], defined as "the use of game design elements in non-game contexts". The application of the "gamification" method to the teaching environment has been analyzed by several authors, and the elements mostly identified were identified: game mechanics, application type, education level, subject, implementation and obtained the results obtained by students [17].

2.2. Emotion

A number of recent studies state both negative and positive emotionally arousing events are better remembered than emotionally neutral events [18–20]. Thus, "Emotional memory is the result of storing the information that was accompanied by stressful factors through which the information is more easily fixed" [21].

The stimuli connected to emotions affecting an individual's feelings can persist in memory with higher intensity than those not linked to emotion [22]. Additionally, they can help with memory retention and the recall of information linked to those events or stimuli [23].

2.3. Educational Escape Rooms and Motivation

An Escape Room (ER) is a game in which a team of players cooperatively discover clues, solve puzzles, and accomplish tasks in one or more rooms in order to progress and accomplish a specific goal in a limited amount of time [24]. Escape Rooms are Live-Action Games that engage directly with the game world, and they match the learning environment of the classroom perfectly, as recent publications point out. Educational Escape Rooms (EER) propose challenges with educational approaches in which students are organized in teams to solve puzzles and challenges associated with the content of the curriculum in a limited time [25]. They offer more motivation and engagement than traditional educational games [26]. At the higher education level (high school and university) in which games are not often played in the classroom, ERs offer sophistication and novelty to teaching practices that students value and appreciate. The published EER experiences that are being applied worldwide at a university-/college-level report positive feedback from students.

The Escape Room activity is categorized either as "gamification" by some authors [3,27–31] or as "serious game" by others [9,32–36]. Both techniques, "serious game" and "gamification", share a main goal, i.e., to foster motivation and create engagement. Their differences are well described in the literature [8]. Furthermore, when applied to the education field, EER is also considered a problem-based learning (PBL), since its features are also included in the ER scenario: "ill-structured problem", "real-life" scenario, open-ended tasks, student autonomy and student collaboration [26].

The Escape Room is a tool that is being used in various fields including the disciplines known as STEM: science, technology, engineering and mathematics [37], as well as numerous and recent escape room experiences in health sciences [25,38,39]. However, despite the numerous studies reporting the application of game tools in Economics and Business fields, no Educational Escape Rooms are found in the literature.

The essential elements of an Escape Room are: (1) the escape rooms (one or several chained or multilinear rooms); (2) challenges, riddles or tasks (various elements whose resolution lead to the exit); (3) physical/online items (to solve tasks within the escape room); (4) game master (people in charge of guiding the participants if required, by offering hints); (5) narrative (common thread of the game that relates all the challenges). In the Educational Escape Room, the design is simplified if the narrative does not act as a common thread that relates all the challenges; however, this is less immersive because the narrative itself motivates the player to live the experience [25].

The game master (GM) is the "big brother" of the ER activity, and EER's game master is not the exception. The game master has to determine the balance of guidance during the game, and he/she conforms the guidance's intensity by estimating the players' skill level [40]. The game master's skill is determined by the coincidence of the estimated time to solve the challenge with the reality.

The better the EER is designed, the less game-master implication is required. Frustration is the only negative feeling students could find during the performance of the EER, since students should be able to solve the challenges and puzzles. There are four facets a game-master must have to succeed in the EER performance. Firstly, the correct design of the challenges so that the time limit coincides with an appropriate amount of time for the level of ability of the students. Teachers should communicate with their students that the activity is going to be considered for the subject assessment, since it is important to encourage students to study and prepare for the activity [29]. Secondly, the story behind the game should engage the students and their choices should be linked to implications; making the players matter is key to designing a successful ER [26]. Thirdly, during the activity, the GM should gather the information regarding the timing and students' attitudes, looking for features to improve the next EER's design. Fourthly, the facet of guiding the students teams during the activity, to control the correct performance and to give hints or clues when needed. Generally, students prefer not to receive any guidance from the GM but instead become immersed in an auto-guided activity [40].

Motivation

Gaming encourages students to persist in the task and offers a type of learning context, two conditions which are essential for deep learning engagement. EER persuades students to think about the material in a new way, which suggests that the potential benefit of ER goes beyond a mere novelty factor [41].

In general, traditional teaching methodologies such as simple exposure of content on a blackboard, through lessons, PowerPoint presentations and textbooks alone do not motivate today's students, who are Millennials or belong to Generation Z, to engage in a topic. Since Millennial students yearn for active engagement and they are motivated by achievement and affiliation, designing EER challenges becomes a highly compelling activity, which increases their interest on the subject [28,42,43].

A review of the recent literature shows that the main positive effect of EER consists of the increase in the motivation of students [26,27,29,40,44]. Nevertheless, further benefits are identified:

- Commitment and participation of students in the subject [44];
- Enhancing group cohesion, commitment, activation, and absence of a negative effect during the teaching and learning process [44];
- Encouraging teamwork, facilitating communication, and promoting professionalism [34];
- Engaging students in their learning environment, and encouraging collaboration, leadership and social skill set development [28];
- Encouraging students to get to know each other [45].

Due to EER's high intrinsic motivation for learning, several authors invite other disciplines to apply it [40,44,46]. Compared to traditional teaching methods, students feel engaged in problem solving, they are focused on their main goal, and they aim to succeed, which requires to successfully communicate with the rest of the team, as well as collaborate and use their social skills.

In order to encourage students to review the course material before the EER performance, including the activity as a part of the subject's assessment is a key factor [28,29].

3. Methodology

The study was carried out in the 2019–2020 academic year among 56 students enrolled in the subject "Introduction to Business" as part of the Marketing Degree, during six weeks in November–December.

The objective of the subject is to provide the student with a vision of the reality in which the business world operates and also to ease the students into understanding and analysis of the management task as a role to play in their future professional career. The assessment system of the subject consists of continuous evaluation (20%), plus a final theoretical exam (40%) and a practical exam (40%).

The subject is taught mainly via face-to-face teaching in class. However, theoretical materials and other practical tests are found in a university online learning platform. The online site used was Moodle, a Learning Management System (LMS).

A special end of semester session was organized in order to strengthen knowledge, motivate students and to generate emotions, bringing better knowledge retention. The class was split into two groups, control and experimental. The second group was introduced to an Educational Hall Escape (EHE), while the control group worked on the same topics, having to resolve the same exercises, but delivered with ordinary format in plain text. Both groups were required to use the same practical knowledge learnt in class during previous weeks. The educational objective of the activity performed, both in the control and experimental groups, was to reinforce specific knowledge of the subject, working on aspects such as emotion and motivation in the experimental group.

3.1. Educational Hall Escape

The study used the application of an Educational Hall Escape (EHE), a version of the standard educational escape room games [26]. This nomenclature does not exist in past scientific literature; however, it is used to differentiate from traditional commercial escape room dynamics. Aspects that they have in common are the fact they are carried out in a locked space, and the narrative flowing through a chain of puzzle/riddles to solve. The aim is to solve the riddles to win the game, not escaping from the room itself.

In the proposed EHE, students had to solve several consecutive conundrums without leaving the room by being quicker than the rest of the teams within a given set time.

The puzzles followed a theme that connected and gave consistency to the whole practice, and they were linked to the subject syllabus. Riddles had to be solved not solely by acquired subject knowledge but also by applying observation, ingenuity and teamwork.

Figure 1 shows the design and order of the activities that shape the EHE. It contains eight puzzles; six of them (from 2 to 7) have an educational objective linked to specific contents of the subject, as indicated in the figure. The other two puzzles (1 and 8) are the ones used to start the EHE and to end it. In addition, some complementary playful tests are collected that support the narrative of the EHE in elliptical form within Figure 1.

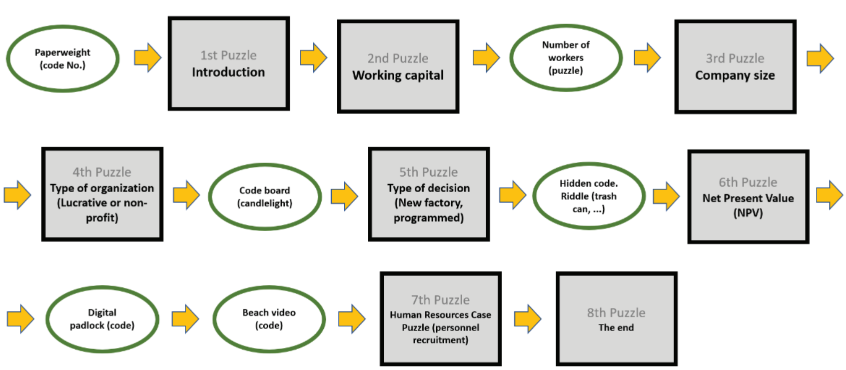


Figure 1. Organization and content of the different activities carried out in the EHE.

In terms of narrative, the chosen theme was appropriate for the student profiles as it was replicable in future learning. Students were given a job offer from an important multinational company to replace the current management team, due to retirement.

For those students who took part in the EHE, the experience started with the viewing of a short introductory video where the lecturers presented the plot, instructions and rules [47]. The quickest team in solving the riddles would be the winner and they would be hired as the company's new management team. Once the video was shown, a countdown was launch displaying the remaining time of the game.

The supporting test (Figure 1—ellipses) starts with a riddle which is hidden in a paperweight. Students must introduce the answer of the riddle into the digital platform to start the game. In addition, other tests were developed and completed during the activity, such as physical puzzles, codes that should be decrypted, riddles hidden into physical objects in the room (Figure 2), a digital padlock in a web and a video which hides a code inside of the narrative.

Figure 2. Examples of tests performed at the EHE.

3.2. Physical Organization

Two separate classrooms were booked in different locations to prevent any interference between both groups; one for the control group and a second one for the EHE group. The day before the activity, the students from both groups were told individually the time and location they had to go to.

The control group attended the usual classroom with the traditional master class layout. The control group was divided into five groups, each of which had five or six members. Each group was given a unique paper document with the activity description in the form of written questions. The questions, in terms of subject content, were identical to the riddles the second group had to solve. However, the dynamics of the activity differed, eliminating time pressure and narrative, both in the texts and in the questions from the whole practice. They did not visualize the introductory video and the lecture was presented as a traditional practical lecture, without games or emotions.

The experimental group attended a side classroom, smaller than standard lecture rooms and with a versatile layout. The room was decorated to create ambience and gain engagement from the students/players. The room had five stations, one for each team.

Each team had few physical elements required to solve some of the challenges in the EHE (such as conundrums or keys placed strategically in some objects inside the room). Each team had a laptop with access to the university virtual learning site where the challenges were found. Along with these, some accessories needed for the activity such as a paperweight with a code, a list of companies with additional information, a sheet with codes, a puzzle and other objects not intended to distract the participants' attention. The lecturers took the role of game master by being available to the teams as required.

The maximum duration of the activity was 50 min. The winning team would be the one that completed the activity the quickest.

3.3. Virtual Organization

The control group did not have access to the university learning online platform during the activity. The experimental group had access to the university online learning platform (Moodle) during the exercise so they could register the solutions to the challenges. This allowed them to have feedback on their progress and let lecturers monitor their movements and results for the study.

The Moodle tool "lessons" was used to implement the virtual side of the EHE. This tool allows the creation of sequential pages with content or questions and to branch out itineraries. In order to create separate records for each team, within the initial lesson and from the first challenge, each team followed a customized itinerary.

Across the respective itineraries' pages, the information needed to solve the challenges was becoming available once feedback was received for correct answers. Questions were used to check the content of the lessons had been absorbed by the students and had two formats: multiple-choice or numeric. In the multiple-choice questions, students had to select the correct answer from a list of 15 items to be able to pass to the next question. For each mistaken answer, the page went back to the original list rearranged, in order to prevent aleatory choices. In addition, a digital locker was used for one of the challenges, directing correct responses to a YouTube video with a hint to move forward.

Figure 3 shows the EHE Moodle design of one of the teams' itineraries. The other ones followed the same structure.

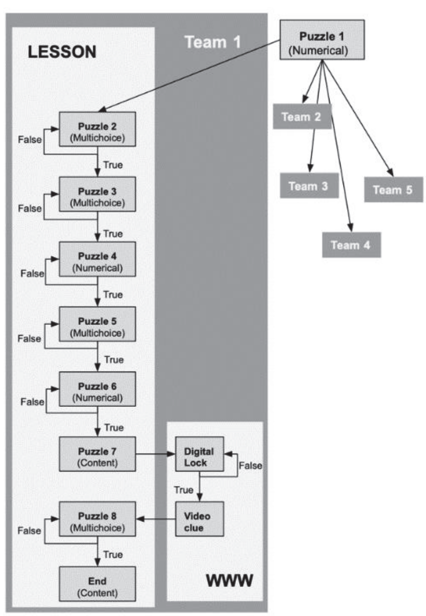


Figure 3. EHE design (lesson) in Moodle.

During the activity, students were allowed to consult their personal notes.

3.4. Study Design

3.4.1. Participants

For the design and validation of the activity, the class was divided into two groups, each of 28 students, created randomly, with a total of 56 participants. One group was experimental, and the second group was the control. Randomly, students were grouped into teams of five and six participants and subsequently assigned to the two main groups of study.

3.4.2. Procedure

The experimental group had an hour and a half, and the control group had an hour and twenty-five minutes to carry out the EHE. Both groups spent the last twenty minutes completing a questionnaire about the session held in Moodle. Time organization is shown in Figure 4.

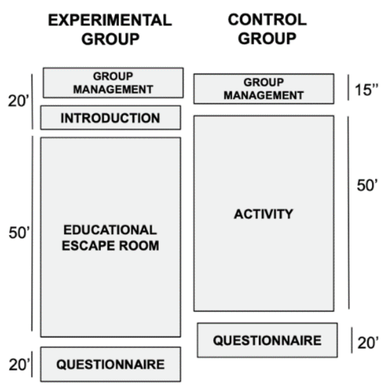


Figure 4. Temporal organization of the experiment.

In terms of analyzing the results and validation of the hypothesis, the study used three tools. Firstly, an exam carried out two weeks post-study. The exam consisted of a 20-question test, where students had to select answers from a four-item list and a penalty for incorrect answers. Seven of the questions were very similar for both the control group and the group taking the EHE. The idea was to verify the knowledge retention in both groups.

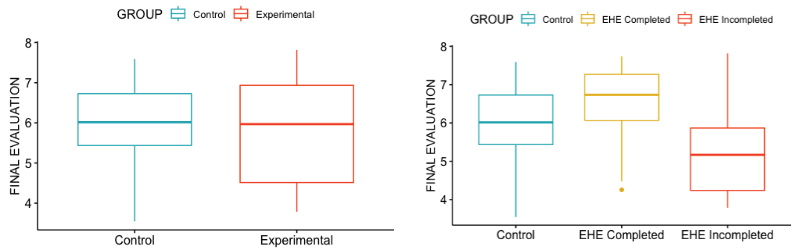
The second analytical tool, used to measure aspects such as motivation and emotion, was the Gameful Experience Questionnaire, Gamefulquest [48], based on 56 items organized in seven categories (Accomplishment, Challenge, Competition, Guided, Immersion, Playfulness and Social experience). This questionnaire measured the individual user's game experience in systems, here the EHE.

4. Results

Statistical analysis was performed using the computing environment R [49] and in particular the R-Likert library [50], for the questionnaire data.

4.1. Testing Hypothesis H1

In order to check whether the learning is greater for those students who enrolled in the EHE experience when compared to those who did not (Hypothesis H1), we consider the final evaluation of the subject. Figure 5a shows boxplots of final evaluation results for both control and experimental groups and a parametric t-test was performed showing that there were no significant differences between Control and Experimental groups (p-value = 0.3433).



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

Figure 5. (**a**) Boxplots of final evaluation results for both Control and Experimental groups; and (**b**) Boxplots of final evaluation results for Control and EHE Completed and EHE Not completed groups.

We also considered whether students participating in the EHE completed the experiment or not. Again, Figure 5b shows differences in the final evaluation between control/completed EHE and not completed EHE students. An analytical analysis shows that there are no significant differences between the three groups (p-value = 0.167) and when considering groups two by two, we observed that the students not completing the EHE experience differ from the other two groups. Table 1 shows numerical summaries of final evaluation for the different groups considered (Control, Experimental, EHE Completed and EHE Not Completed).

Table 1. Numerical summaries of final evaluation for the different groups considered (Control, Experimental, EHE completed and EHE Not Completed): minimum (Min), 1st quantile (Q1), median (Med), Mean, 33rd quantile (Q3), maximum (Max) and standard deviation (SD)).

	Min	Q1	Med	Mean	Q3	Max	SD
Control	3.548	5.436	6.016	6.050	6.728	7.588	1.032
Experimental (EHE)	3.788	4.514	5.968	5.839	6.934	7.816	1.350
EHE Completed	4.256	6.068	6.736	6.386	7.268	7.740	1.257
EHE Incompleted	3.788	4.240	5.168	5.291	5.868	7.816	1.272

4.2. Testing Hypothesis H2

As mentioned above, after the EHE experience, students responded to a questionnaire based on 56 questions. The Gamefulquest [48] and the 56 questions are arranged in seven well-known dimensions: Accomplishment, Challenge, Competition, Guided, Immersion, Playfulness and Social Experience. A seven-point Likert-type scale was used for each question, ranging from "(1) strongly disagree" to "(7) strongly agree."

Out of the total of 56 students, only 47 students completed both the questionnaire and the evaluation process, 25 from the Control group and 22 from the experimental group (12 of which completed the experience and 10 did not).

For each of the 56 questions, we analyzed whether there were significant differences between the control and the hall escape groups (Hypothesis H2). To do this, we used both graphical and inferential methods. Whether a parametric or nonparametric test should be employed, for analyzing questionnaire data, has been somehow controversial. Many authors argue that for such discrete ordinal variables, a nonparametric test should be used. However, other authors argue that parametric tests are more robust and could also be employed for Likert data under some premises such as normality assumptions not being violated; see for instance Sullivan et al. [51].

After checking normality for each of the 56 different questions of the questionnaire, employing both graphical inspection (Q–Q plots) and two normality tests (the Kolmogorov–Smirnov test and the Shapiro–Wilk's W test) we concluded that nonparametric Mann–

Whitney tests would be better used here and, therefore, Mann–Whitney tests were employed for testing significant differences between control and experimental groups in each one of the 56 questionnaire responses. Only 16 out of the 56 Mann–Whitney tests developed seem to be not significant (p-values > 0.05), which allows us to conclude that responses from students who took part in the EHE experiment differ markedly from those who did not took part in the gaming experience along with the seven dimensions of the questionnaire.

4.3. Testing Hypotheses H3 and H4

Apart from the seven dimensions considered in the Gamefulquest questionnaire, in this research we are especially interested in two particular aspects, namely motivation and emotion. Out of the 56 questions, we identified 13 questions related to emotion (Hypothesis H3) and 13 related to motivation (Hypothesis H4). Figures 6 and 7 present results of the questionnaire for the questions related to motivation and emotion, respectively.

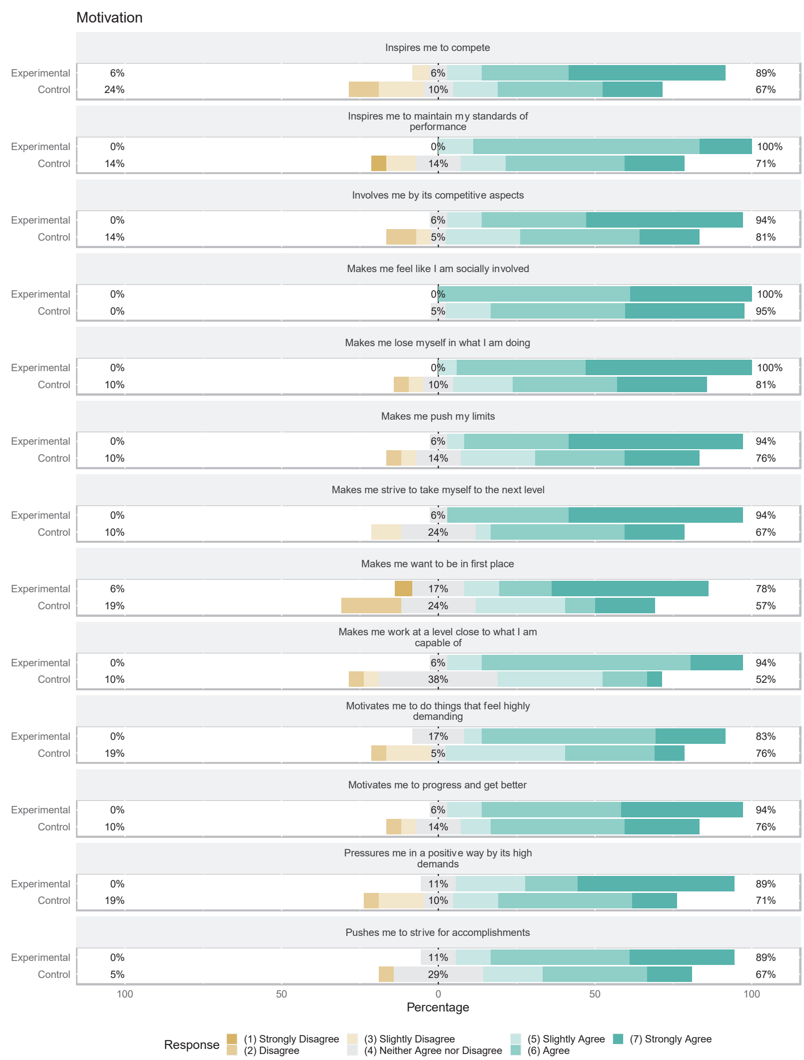


Figure 6. Questionnaire questions related to motivation.

All these 26 questions show significant differences between the Escape Room and control students, i.e., p-values < 0.05 in the corresponding Mann–Whitney tests.

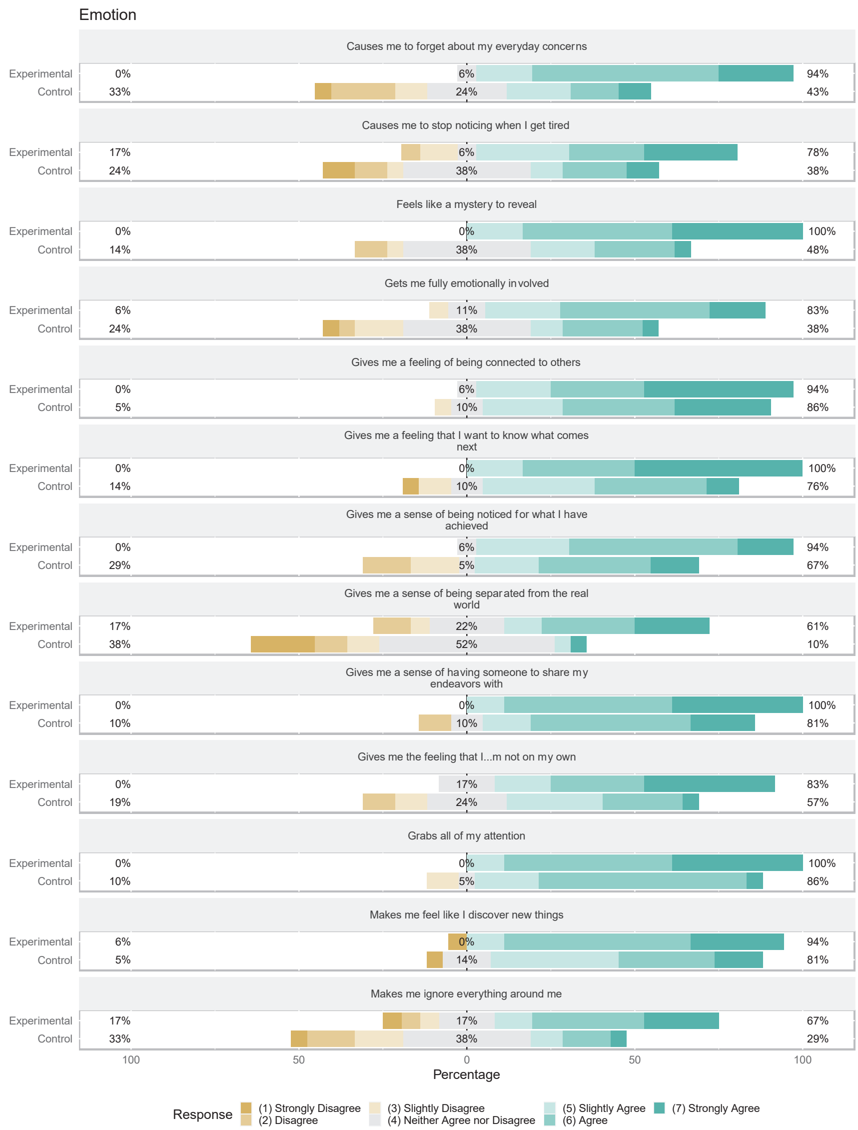
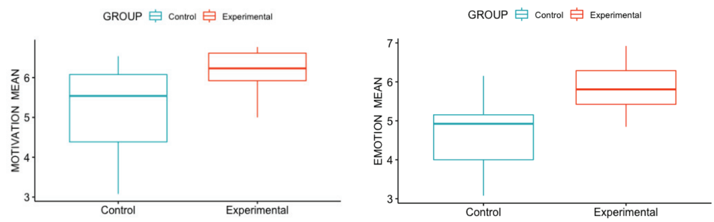


Figure 7. Questionnaire questions related to emotion.

For the sake of completeness, and in order to define a quantitative variable measuring the Motivation and Emotion aspects of interest, we calculated the mean responses of those questionnaire items already identified as motivation or emotion questions. As expected, these two variables show significant differences between escape room and control students. Here, we use parametric t-test after checking normality premises are met (again using Q–Q plots and the Kolmogorov–Smirnov test and the Shapiro–Wilk's test). Boxplots presented in Figure 8a,b, showing graphical evidence and statistical test conclude that questionnaire responses are higher for experimental than control students with p-values < 0.001 for both motivation and emotion.



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

Figure 8. (**a**) Boxplot showing graphical evidence that the motivation questionnaire responses are higher for the experimental than the control group; and (**b**) Boxplot showing graphical evidence that the emotion questionnaire responses are higher for the experimental than the control group.

For the sake of completeness, Tables 2 and 3 show summary statistics for the mean responses of those questionnaire items identified as motivation or emotion questions.

Table 2. Numerical summaries for the mean responses of those questionnaire items identified as motivation for control and experimental groups: minimum (Min), 1st quantile (Q1), median (Med), Mean, 33rd quantile (Q3), maximum (Max) and standard deviation (SD)).

	Min	Q1	Med	Mean	Q3	Max	SD
Control	3.077	4.385	5.538	5.253	6.077	6.538	1.062
Experimental	5.000	5.923	6.231	6.176	6.615	6.769	0.522

Table 3. Numerical summaries for the mean responses of those questionnaire items identified as emotion for control and experimental groups: minimum (Min), 1st quantile (Q1), median (Med), Mean, 33rd quantile (Q3), maximum (Max) and standard deviation (SD)).

	Min	Q1	Med	Mean	Q3	Max	SD
Control	3.077	4.000	4.923	4.692	5.154	6.154	0.772
Experimental	4.846	5.423	5.808	5.829	6.288	6.923	0.553

5. Discussion and Conclusions

The research design is based on four hypotheses and their rejection and validation are shown. In addition, the Educational Hall Escape experience presented is easy to adapt, not only in higher education and business economics fields, but also in other subjects, disciplines and educational levels.

When dealing with EHE configuration and results, it is important to analyze the participants' progress and register their activity.

Several EHE aspects could be assessed by analyzing the results of the students, such as the level and puzzle adaptation, or the allotted time. To obtain this information, a virtual space in Moodle registered, monitored and recorded the students activity. This type of virtual resource offers the possibility of sending automatic feedback to students, to guide them during the process, either when the answer is correct or not, and determine whether or not they have to repeat the puzzle. Thus, a physical and a digital duality is conferred upon the experience, by combining tests with touchable elements, giving a more realistic context to the narrative, with other digital resources.

Teachers should pay attention to every event taking place inside the room and in the different teams in order to avoid a loss of motivation and to keep the students focused on the main goal of the objective of the activity, which is to generate emotions. In order to be able to do this, a minimum of two teachers must participate in the EHE and one of them must become the game master. Other studies in the literature underline the role of the game master during the performance of EER [40,52], since this figure offers extra guidance.

The first defined hypothesis deals with the improvement of the learning process of the experimental group that performed the EHE. In H1, it is stated that this group would achieve better results than the control group. The experiment looked for the students' emotional stimulation to improve their knowledge retention and memory. A number of recent studies state both negative and positive emotionally arousing events are better remembered than emotionally neutral events [18–20]. Thus, "Emotional memory is the result of storing the information that was accompanied by stressful factors through which the information is more easily fixed" [21]. The results, shown in Figure 5a,b, reject the hypothesis. Despite the fact that the exam results are slightly better for those who successfully finished the EHE, there is no statistical significance. The students who did not finish the EHE achieved worse results, but these are not significant. Thus, it is confirmed that applying this strategy does not worsen students' learning results when the experimental group is compared to the control group, provided that students finish the activity. It is of interest to recall here that the gaming experience took place in just a 2 h session and therefore we could not expect this to have a significant effect upon the whole evaluation of the semester. This lack of positive academic results is found in similar Educational Escape Room experiences reported in the literature [45,52,53].

The second hypothesis (H2) tries to answer whether EHE participants felt the game in all its dimensions, following the seven emotions once defined by Högberg et al. (2019) in a designed and validated questionnaire [48]. As a result, a remarkable game perfection difference was measured between the experimental and the control groups. It is clear from the outcome the appropriate design of the experimental activity strengthens the feelings generated by games, such as the motivation and the emotions that this research fosters. Despite the fact that there are other questionnaires, such as the one proposed by Hou and Chou [54] or GAMEX [55], that measure a number between two and five dimensions, they share the same goal, which is getting to know the game experience.

The last two hypotheses deal with two aspects that are key to this work, i.e., motivation (H3) and emotion (H4). As expected, the experimental group exhibits significatively better results for both cases, summarized in Figure 8a,b boxplots.

Using Escape Room as an educational strategy to foster student motivation is widely proposed in the literature [40,44,55], since it engages the students and maintains their attention.

Educational Hall Escape is based on the Educational Escape Room, providing two important extras:

- the existence of several teams competing to achieve the same challenge at the same time and place; and
- the condition of leaving the room as the final goal is eliminated.

Thus, the possibilities of this strategy for working on more skills than EER are slightly higher provided that the main features of it are kept, such as the room, the puzzles and the narrative.

Even though here it was demonstrated that the learning is not improved by the EHE, due to its brief application, the motivation of the students and their emotions increased notably. This fact can be used to engage the students with the subject.

The study presented here shows an experience that can be easily replicated in other fields, producing a positive impact on the motivation of the students who participate in the experiment, i.e., EHE, instead of the traditional class. The main limitation of this research is the lack of academic results linked to emotions, even though the motivation increases, as previously mentioned. From the results and detected limitations, future work is proposed to take advantage of the motivation improvement during these types of games, in which the students become involved in the subject, by re-scheduling the activity to the start of the term. Hence, these types of strategies would be recommended for the beginning of the course, as a reason for introducing students to the topic and contents. On the other hand, since the proposed activity is generic, focused on reviewing some concepts, we propose changing the main educational objective by focusing it on the learning of new concepts. The new objective not only would imply a support to understand already seen concepts, but also look at new ones, at the time that an active and autonomous attitude of the student is obtained. This type of activity would replace the classic classroom teaching method at times.

Author Contributions: Conceptualization, A.M.-G. and O.B.-G..; theoretical background, L.S.-L. and A.M.-G.; methodology, A.M.-G. and O.B.-G.; validation, R.M.D.; formal analysis, R.M.D.; investigation, A.M.-G. and O.B.-G.; data curation, R.M.D.; writing—original draft preparation, all authors; writing—review and editing, L.S.-L. and R.M.D.; supervision, O.B.-G. All authors have read and agreed to the published version of the manuscript.

Funding: This work has been co-funded by the Madrid Regional Government, through the project e-Madrid-CM (P2018/TCS-4307). The e-Madrid-CM project is also co-financed by the Structural Funds (FSE and FEDER).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

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

References

1. Berrocoso, J.V. *Aprendizaje de la Historia y Simulación Educativa*; Tejuelo Didáctica Leng. Lit. Educ.; Repositorio Institucional Universidad de Extremadura: Dehesa, Spain, 2010; pp. 83–99.
2. Daza, M.C.S.; Fernández-Sánchez, M.R. Gamificando el aula universitaria. Análisis de una experiencia de Escape Room en educación superior. *REXE Rev. Estud. Exp. Educ.* **2019**, *18*, 105–115.
3. Borrego, C.; Fernández, C.; Blanes, I.; Robles, S. Room Escape at Class: Escape Games Activities to Facilitate the Motivation and Learning in Computer Science. *J. Technol. Sci. Educ.* **2017**, *7*, 162–171. [CrossRef]
4. Rogers, S.; Evans, J. *Inside Role-Play in Early Childhood Education: Researching Young Children's Perspectives*; Routledge: Abingdon, UK, 2008; ISBN 978-1-134-13654-4.
5. Lim, J. Fun, Games & Economics: An Appraisal of Game Theory in Economics. *Univ. Ave. Undergrad. J. Econ.* **1999**, *3*, 7.
6. Cournot, A.A. *Recherches Sur Les Principes Mathématiques de La Théorie des Richesses*; L. Hachette: Paris, France, 1838.
7. McDonald, J. *The Game of Business*; Doubleday: New York, NY, USA, 1975; ISBN 978-0-385-09008-7.
8. Mayer, I. *Playful Organisations & Learning Systems*; Breda University of Applied Sciences: Breda, The Netherlands, 2016.
9. Fleming, T.M.; Bavin, L.; Stasiak, K.; Hermansson-Webb, E.; Merry, S.N.; Cheek, C.; Lucassen, M.; Lau, H.M.; Pollmuller, B.; Hetrick, S. Serious Games and Gamification for Mental Health: Current Status and Promising Directions. *Front. Psychiatry* **2017**, *7*, 215. [CrossRef] [PubMed]
10. Uskov, A.; Sekar, B. Serious Games, Gamification and Game Engines to Support Framework Activities in Engineering: Case Studies, Analysis, Classifications and Outcomes. In Proceedings of the IEEE International Conference on Electro/Information Technology, Milwaukee, WI, USA, 5–7 June 2014; pp. 618–623.
11. Gloria, A.D.; Bellotti, F.; Berta, R. Serious Games for Education and Training. *Int. J. Serious Games* **2014**, *1*, 1. [CrossRef]
12. Kiryakova, G.; Angelova, N.; Yordanova, L. Gamification in Education. In Proceedings of the 9th International Balkan Education and Science Conference, Istanbul, Turkey, 24–27 August 2014.
13. Healey, D. *Gamification White Paper*; Macmillan Education: 2019. Available online: https://www.macmillaneducation.es/wp-content/uploads/2019/04/Gamification-White-Paper_Mar-2019.pdf (accessed on 17 May 2021).
14. Marczewski, A. *Even Ninja Monkeys Like to Play: Unicorn Edition*, 1st ed.; Gamified: London, UK, 2018; ISBN 978-1-72401-710-9.
15. Silva, E. *Gamifying Learning with Social Gaming Mechanics*; CreativeCommons: Mountain View, CA, USA, 2010; pp. 61–62.
16. Deterding, S.; Dixon, D.; Khaled, R.; Nacke, L. From Game Design Elements to Gamefulness: Defining "Gamification". In Proceedings of the 15th International Academic MindTrek Conference: Envisioning Future Media Environments, Tampere, Finland, 28 September 2011; pp. 9–15.
17. Dicheva, D.; Dichev, C.; Agre, G.; Angelova, G. Gamification in Education: A Systematic Mapping Study. *Educ. Technol. Soc.* **2015**, *18*, 75–88.
18. Cahill, L.; Prins, B.; Weber, M.; McGaugh, J.L. Beta-Adrenergic Activation and Memory for Emotional Events. *Nature* **1994**, *371*, 702–704. [CrossRef]
19. Romeu, P.F. Recuerdo de imágenes emocionales y niveles de procesamiento. *Psicothema* **2002**, *14*, 591–596.

20. Lago, J.M.R.; Rey, J.F. Reconocimiento de fotografías de contenido emocional: Efectos de la valencia cuando se controla el arousal. *Psicológica Rev. Metodol. Psicol. Exp.* **2010**, *31*, 65–86.
21. Justel, N.; Psyrdellis, M.; Ruetti, E. Modulación de la memoria emocional: Una revisión de los principales factores que afectan los recuerdos. *Suma Psicológica* **2013**, *20*, 163–174. [CrossRef]
22. Steidl, S.; Razik, F.; Anderson, A.K. Emotion Enhanced Retention of Cognitive Skill Learning. *Emotion* **2011**, *11*, 12–19. [CrossRef]
23. Geake, J. Educational Neuroscience and Neuroscientific Education: In Search of a Mutual Middle Way. In *Research Intelligence*; University of New England: Biddeford, ME, USA, 2005.
24. Nicholson, S. Peeking behind the Locked Door: A Survey of Escape Room Facilities. 2015. Available online: https://scottnicholson.com/pubs/erfacwhite.pdf (accessed on 17 May 2021).
25. Manzano-León, A.; Rodríguez-Ferrer, J.M.; Aguilar-Parra, J.M.; Martínez Martínez, A.M.; Luque de la Rosa, A.; Salguero García, D.; Fernández Campoy, J.M. Escape Rooms as a Learning Strategy for Special Education Master's Degree Students. *Int. J. Environ. Res. Public Health* **2021**, *18*, 7304. [CrossRef] [PubMed]
26. Nicholson, S. Creating Engaging Escape Rooms for the Classroom. *Child. Educ.* **2018**, *94*, 44–49. [CrossRef]
27. Gómez-Urquiza, J.L.; Gómez-Salgado, J.; Albendín-García, L.; Correa-Rodríguez, M.; González-Jiménez, E.; Cañadas-De la Fuente, G.A. The Impact on Nursing Students' Opinions and Motivation of Using a "Nursing Escape Room" as a Teaching Game: A Descriptive Study. *Nurse Educ. Today* **2019**, *72*, 73–76. [CrossRef] [PubMed]
28. Kinio, A.E.; Dufresne, L.; Brandys, T.; Jetty, P. Break out of the Classroom: The Use of Escape Rooms as an Alternative Teaching Strategy in Surgical Education. *J. Surg. Educ.* **2019**, *76*, 134–139. [CrossRef] [PubMed]
29. López-Pernas, S.; Gordillo, A.; Barra, E.; Quemada, J. Examining the Use of an Educational Escape Room for Teaching Programming in a Higher Education Setting. *IEEE Access* **2019**, *7*, 31723–31737. [CrossRef]
30. Vörös, A.I.V.; Sárközi, Z. Physics Escape Room as an Educational Tool. In *AIP Conference Proceedings*; AIP Publishing LLC: New York, NY, USA, 2017. Available online: https://aip.scitation.org/doi/abs/10.1063/1.5017455 (accessed on 17 May 2021).
31. Lathwesen, C.; Belova, N. Escape Rooms in STEM Teaching and Learning—Prospective Field or Declining Trend? A Literature Review. *Educ. Sci.* **2021**, *11*, 308. [CrossRef]
32. Brown, N.; Darby, W.; Coronel, H. An Escape Room as a Simulation Teaching Strategy. *Clin. Simul. Nurs.* **2019**, *30*, 1–6. [CrossRef]
33. Connelly, L.; Burbach, B.E.; Kennedy, C.; Walters, L. Escape Room Recruitment Event: Description and Lessons Learned. *J. Nurs. Educ.* **2018**, *57*, 184–187. [CrossRef]
34. Friedrich, C.; Teaford, H.; Taubenheim, A.; Boland, P.; Sick, B. Escaping the Professional Silo: An Escape Room Implemented in an Interprofessional Education Curriculum. *J. Interprof. Care* **2019**, *33*, 573–575. [CrossRef]
35. Humphrey, K. The Application of a Serious, Non-Digital Escape Game Learning Experience in Higher Education. *Sport Exerc. Psychol. Rev.* **2017**, *13*, 48–54.
36. Warmelink, H.; Mayer, I.; Weber, J.; Heijligers, B.; Haggis, M.; Peters, E.; Louwerse, M. AMELIO: Evaluating the Team-Building Potential of a Mixed Reality Escape Room Game. In Proceedings of the Extended Abstracts Publication of the Annual Symposium on Computer-Human Interaction in Play, Amsterdam, The Netherlands, 15–18 October 2017; ACM: New York, NY, USA, 2017; pp. 111–123.
37. Yllana-Prieto, F.; Jeong, J.S.; González-Gómez, D. An Online-Based Edu-Escape Room: A Comparison Study of a Multidimensional Domain of PSTs with Flipped Sustainability-STEM Contents. *Sustainability* **2021**, *13*, 1032. [CrossRef]
38. Morrell, B.L.M.; Ball, H.M. Can You Escape Nursing School? Educational Escape Room in Nursing Education. *Nurs. Educ. Perspect.* **2020**, *41*, 197–198. [CrossRef] [PubMed]
39. Monaghan, S.; Nicholson, S. Bringing Escape Room Concepts to Pathophysiology Case Studies. *HAPS Educ.* **2017**, *21*, 49–65. [CrossRef]
40. Giang, C.; Chevalier, M.; Negrini, L.; Peleg, R.; Bonnet, E.; Piatti, A.; Mondada, F. Exploring Escape Games as a Teaching Tool in Educational Robotics. In Proceedings of the Educational Robotics in the Context of the Maker Movement, Rome, Italy, 11 October 2018; Moro, M., Alimisis, D., Iocchi, L., Eds.; Springer International Publishing: Cham, Switzerland, 2020; pp. 95–106.
41. Eukel, H.N.; Frenzel, J.E.; Cernusca, D. Educational Gaming for Pharmacy Students—Design and Evaluation of a Diabetes-Themed Escape Room. *Am. J. Pharm. Educ.* **2017**, *81*, 6265. [CrossRef]
42. Jambhekar, K.; Pahls, R.P.; Deloney, L.A. Benefits of an Escape Room as a Novel Educational Activity for Radiology Residents. *Acad. Radiol.* **2020**, *27*, 276–283. [CrossRef]
43. Olszewski, A.E.; Wolbrink, T.A. Serious Gaming in Medical Education: A Proposed Structured Framework for Game Development. *Simul. Healthc.* **2017**, *12*, 240–253. [CrossRef] [PubMed]
44. López-Belmonte, J.; Segura-Robles, A.; Fuentes-Cabrera, A.; Parra-González, M.E. Evaluating Activation and Absence of Negative Effect: Gamification and Escape Rooms for Learning. *Int. J. Environ. Res. Public Health* **2020**, *17*, 2224. [CrossRef]
45. Clarke, S.; Arnab, S.; Morini, L.; Wood, O.; Green, K.; Masters, A.; Bourazeri, A. EscapED: A Framework for Creating Live-Action, Interactive Games for Higher/Further Education Learning and Soft Skills Development. In Proceedings of the 10th European Conference on Games Based Learning, Paisley, UK, 6–7 October 2016; pp. 968–972.
46. Cain, J. Exploratory Implementation of a Blended Format Escape Room in a Large Enrollment Pharmacy Management Class. *Curr. Pharm. Teach. Learn.* **2019**, *11*, 44–50. [CrossRef]
47. Borrás-Gené, O. *IB International Marketing Escape Room [Slides]*; Slideshare: Madrid, Spain, 2019. Available online: https://es.slideshare.net/oriolupm/escapando-del-aula (accessed on 15 May 2021).

48. Högberg, J.; Hamari, J.; Wästlund, E. Gameful Experience Questionnaire (GAMEFULQUEST): An Instrument for Measuring the Perceived Gamefulness of System Use. *User Model. UserAdapt. Interact.* **2019**, *29*, 619–660. [CrossRef]
49. R Core Team. *R: The R Project for Statistical Computing*; R Core Team: Vienna, Austria, 2017.
50. Bryer, J.; Speerschneider, K. *Likert: An R Package Analyzing and Visualizing Likert Item*; GitHub: Vienna, Austria, 2017.
51. Sullivan, G.M.; Artino, A.R. Analyzing and Interpreting Data from Likert-Type Scales. *J. Grad. Med. Educ.* **2013**, *5*, 541–542. [CrossRef] [PubMed]
52. Pearcy, M.; Guise, E.; Heller, D. "Escape the Room"—A Strategy for Problem-Based Learning and Student Inquiry. *Soc. Stud. Res. Pract.* **2019**, *14*, 306–320. [CrossRef]
53. Chang, H.-Y.H. *Escaping the Gap: Escape Rooms as an Environmental Education Tool*; Environmental Sciences at UC Berkeley: Senior Thesis Projects; University of California: UC Berkeley: Berkeley, CA, USA, 2019; p. 35.
54. Hou, H.; Chou, Y.-S. Exploring the Technology Acceptance and Flow State of a Chamber Escape Game—Escape the Lab© for Learning Electromagnet Concept. Available online: /paper/Exploring-the-technology-acceptance-and-flow-state-Hou-Chou/6a0f6e37a44361ac1ed7b4bec22996b1705549ed (accessed on 14 July 2020).
55. Eppmann, R.; Bekk, M.; Klein, K. Gameful Experience in Gamification: Construction and Validation of a Gameful Experience Scale [GAMEX]. *J. Interact. Mark.* **2018**, *43*, 98–115. [CrossRef]

education sciences

MDPI

Article

Using a Cooperative Educational Game to Promote Pro-Environmental Engagement in Future Teachers

Mercedes Vázquez-Vílchez *, Dalia Garrido-Rosales, Beatriz Pérez-Fernández and Alicia Fernández-Oliveras

Departamento de Didáctica de las Ciencias Experimentales, Universidad de Granada, 18071 Granada, Spain; daliagarrido@correo.ugr.es (D.G.-R.); beatrix22@correo.ugr.es (B.P.-F.); alilia@ugr.es (A.F.-O.)
* Correspondence: mmvazquez@ugr.es

Abstract: This paper explores the value of cooperative games in enhancing knowledge and generating pro-environmental engagement in students. For this, an educational board game related to global change was developed, validated, and subsequently evaluated using future primary school teachers. The board game was validated and evaluated in two phases. Phase I (validation phase): students pursuing a Master's Degree in Secondary Education evaluated different aspects of the game, providing feedback that improved the game design and playing rules. Phase II (implementation–evaluation phase): the game was implemented using students of the Primary Education Degree, whose learning performance and engagement was assessed through a qualitative survey. These participants were considered potential users of the board game. The users' experience was explored using a theoretical framework for pro-environmental engagement through playing the game. The findings demonstrate that the cooperative game proposed fomented a feeling of personal responsibility for the environment in the users. It also fostered cognitive, emotional, and behavioural engagement in the players. The results agree with the attributes present in the framework of engagement with respect to climate-change-related issues using gaming. Game-based learning can be used as a tool for enhancing global change knowledge and promoting pro-environmental engagement while bolstering Education for Sustainability (EfS) capacity in future primary-school teachers.

Keywords: game-based learning; board games; global change; environmental engagement; teacher training; higher education; Education for sustainabieducation for sustainabilitylity

Citation: Vázquez-Vílchez, M.; Garrido-Rosales, D.; Pérez-Fernández, B.; Fernández-Oliveras, A. Using a Cooperative Educational Game to Promote Pro-Environmental Engagement in Future Teachers. *Educ. Sci.* **2021**, *11*, 691. https://doi.org/10.3390/educsci11110691

Academic Editors: José Carlos Piñero Charlo, María Teresa Costado Dios, Enrique Carmona Medeiro and Fernando Lloret

Received: 23 August 2021
Accepted: 24 October 2021
Published: 29 October 2021

1. Introduction

Programmes such as the United Nations Decade of Education for Sustainable Development have made global calls to teach about the global environmental crisis, in order to encourage changes in knowledge, values, and attitudes with the vision of building a more sustainable and fairer society for all. These calls, increasingly reflected in formal and non-formal education settings, are expressed in international assessments of science education [1]. However, although the public has been progressively becoming aware of environmental issues, a discrepancy persists between the convictions expressed and the behaviour of large segments of society [2]. Thus, an awareness of an environmental problem is needed to motivate pro-environmental action, which may be strengthened by understanding the link between an individual's actions and subsequent environmental decline [3]. According to Bamberg [4] an important precursor of pro-environmental action is a feeling of personal responsibility for the environment—which also involves being aware of how one's actions negatively impact nature. Such personal environmental norms have been shown to predict pro-environmental behavior, such as choosing sustainable modes of travel [5] and preserving marine environments [6]. In this sense, Education for Sustainability (EfS) should encourage the feeling of personal responsibility to initiate pro-environmental behaviour. Therefore, EfS needs to be established as a key purpose of scholarly education but ensuring good teacher training in EfS is a major challenge [7–9].

This paper explores the role of game-based learning in expanding knowledge and fostering pro-environmental engagement. To this end, an educational board game based on global change (GC) was developed and validated. GC is a complex term still widely confused with climate change. GC refers to the ensemble of environmental changes provoked by human activities, especially changes in the functioning of the Earth's systems. GC includes at least five components: atmospheric composition, soil use, climate, biochemical cycles, and biodiversity. These components are interconnected in such a way that, if one of them is altered, the characteristics of the others will also change [10]. Our study is in line with other authors who propose educational games and gamification for climate-change engagement [11], but no study available has treated climate change as a part of GC, which is key in EfS, since climate-change is only one factor to take into account in order to promote pro-environmental engagement. We implemented the game using students of the Primary Education Degree, while learning performance and engagement were evaluated through a qualitative survey. This paper provides an evidence-based case study that offers insight into the learning and experiences of students after playing an environmental game, which demonstrably enhanced engagement in the future primary teachers. This approach may be of use to others in the sustainability community considering cooperative game-based learning and teaching opportunities.

2. Game-Based Learning and Engagement

2.1. Game-Based Learning Approach

The game-based learning approach has been largely recognized as one of the best active educational approaches [12,13]. It is a type of gameplay with learning outcomes, making it distinct from entertainment-oriented formulas. Game-based learning is designed and developed for the primary purpose of educating or training students [14,15].

Extensive research involving game-based learning provides the empirical evidence that supports diverse cognitive benefits [16–18] accompanied by affective and motivational changes [19,20]; however, some studies qualify this view and suggest that while games have value within teaching and learning, their effectiveness in improving student performance is influenced by the design of the game and the specific instructional purpose [21]. Wouters et al. [22] acknowledged that game-based learning interventions are often short, consisting of only one session and thus limiting their possible learning impact.

Although more research is required to establish the long-term outcomes of games on student achievement and deeper learning [23], there is evidence to suggest that playing games can improve student learning and engagement [24]. Core traits within games offer opportunities to change behaviours and develop learning [25]. These include uncertainty, i.e., the inability to fully predict or control processes related to outcomes, and non-linearity, i.e., the interaction among a game's elements that can generate different outcomes. Games could provide opportunities to change behaviours, develop ideas, and encourage collaboration within the safe environment of a game [24,26], thus, the game can enhance students' experiences and engagement through peer-to-peer learning, collaboration, negotiation, and problem solving [27]. Moreover, game-based learning is a didactic strategy that facilitates experiential learning, given that the users attempt to reproduce a context as close to reality as possible [24]. Experiential learning seeks to engage students through education and entertainment, where students develop critical thinking skills and generate an emotional response. Some authors have highlighted the capability of game-based learning to engage and motivate students who no longer find traditional learning and teaching styles appealing [24–26]. Cooper et al. [28] suggests this is due to games' ability to harness collaborative problem-solving skills. Therefore, student engagement and motivation, so closely related in the learning process, are crucial advantages of game-based learning over traditional instruction, thus, it is only natural that researchers frequently focus on these aspects as a key aspect of instructional games [25,26].

2.2. Engagement and Motivation

The concept of engagement has many connotations. One such example of this is player engagement, which is related to the experience of playing games and linked to a multitude of other concepts such as flow [29], immersion [30] and motivation [31]. On the other hand, the student engagement concept has a multifaceted nature and is defined in three subdomains (behavioral, emotional and cognitive engagement). Behavioral engagement encompasses student participation; it includes involvement in activities and is significant in the achievement of learning outcomes [32,33]. Emotional engagement covers both positive and negative reactions to instructors, classmates, and schools, and it is thought to build connections with others and reflect the willingness of students to complete tasks [31,34]. Finally, cognitive engagement incorporates student investment, and it influences the thoughtful efforts of students to understand complex knowledge and master difficult skills [35,36]. For this study, we have considered the concept of engagement as used in climate change research, specifically that proposed by Lorenzoni et al. [37], who defines engagement with climate change as the individual evaluation of and response to climate change which comprises cognitive, emotional and behavioural components. We have chosen this approach because it comes closest to the aim of our study, as it provides a framework for categorising those responses of our students that show a personal connection not only to climate change, but to other environmental issues included in GC.

Lorenzoni et al. [37] suggests that it is not enough for people to know about climate change, but that "they must also care about it, be motivated and able to act" to engage with climate change. Hence, the definition of engagement includes all three dimensions: cognitive, emotional and behavioural. Thus, in order to become more engaged with climate-change-related issues, in our case GC, players will: (a) think more about and possibly learn more about it (b) feel more personally involved, i.e., give more importance to the issue; and (c) make behavioural changes to express their concern.

The motivation to play is strongly related to motivation grounded in activity specific incentives [38]. In this way, the activities proposed in game-based learning can motivate students, increasing their learning outcomes and problem-solving skills [39]. Game-based learning can also develop both extrinsic and intrinsic motivation in students [40]. Intrinsic motivation is defined as the doing of an activity for its inherent satisfaction rather than for some separable consequence, while extrinsic motivation is incentivized with the acquisition of reinforcers [41]. Game-based learning can increase the student´s intrinsic motivation, for example, when they feel recognition from, and sense of belonging to, a group [42]. Games can also use different mechanics and dynamics, highlighting, for example, the points–badges–leaderboards triad [43] and enhancing extrinsic motivation, which in excess could have a negative impact on the intrinsic motivation of students [41]. In this sense, to keep users engaged is especially important to foment intrinsic motivations [44,45].

2.3. Game-Based Learning for Sustainability

The literature offers many examples of specific game-based learning studies on EfS [11,46–48]. These games address a wide range of learning goals, from increased knowledge to enhanced pro-environmental engagement [49,50], and involve the use of different formats (i.e., digital, board game, and hybrid).

Board games appear to be an excellent learning tool to use for EfS, usually being designed as social activities [11]. According to social constructivist theories, ideas are built through social interaction [51], which is an effective strategy in terms of EfS [52]. Moreover, the board game platform creates a small virtual society in which students can learn by trial and error and accumulate experiences in a virtual world. Based on the scenario around which the theme of a board game is designed, different events can be simulated. Moreover, board games are highly interactive. In these games, students can take the initiative to explore and exchange information with their peers, thus promoting student-centred learning. With board games, participants play face to face, engaging in human-to-human interactions (interactions among players) and human-to-board game interactions (feedback provided to players by board game mechanisms). Students explore the world of the board game and its mechanisms as beginners and, through feedback and player interaction, gradually become familiar with the rules and value systems of the game [48,53,54].

In fact, there are numerous examples of board games that present several opportunities to explore multiple facets of sustainability. For instance, the *Keep Cool* game covers and integrates central biophysical, economic, and political aspects of climate change [52]. *Water Ark*, enhances participants' knowledge about water resources [53]. The theme of the *Crazy Water* board game simulates the water use habits of residents in their daily lives [54]. The *Enviropoly* game works with daily life behaviours, which have negative or positive effects on the environment, promoting environmental literacy [55]. The *Forage Rummy* game can be used to educate farmers in climate change [56]. The *Let's Save Energy*! game is focused on international and environmental cooperation against climate change [57] and, finally, in *Be Blessed in Taiwan* [46,47], sustainable development concepts are introduced into the play process. This board game addresses four related aspects: social development, economic growth, environmental protection, and animal survival. In this paper, we offer a new game based on GC, where its five components are equally addressed, presenting students with a global view of environmental issues, unlike the many climate change games we have identified in the literature [11].

Although sustainability games have begun to be implemented in educational settings, academia knows little about how gaming works with environmental topics, what its characteristics and actual performance are, or how much potential it has to foment awareness, engagement and behavioural change [11,58]. In this way, there are few theoretical frameworks that provide a comprehensive vision of which factors should be considered in games to promote pro-environmental behaviours.

Recently, Ouariachi et al. [59] provided a theoretical framework which indicates those game attributes that should be considered in order to motivate people into action. These attributes are the following: (1) achievable; (2) challenging; (3) concrete; (4) credible; (5) efficacy enhancing; (6) experiential; (7) feedback oriented; (8) fun; (9) identity-driven; (10) levelling-up; (11) meaningful; (12) narrative-driven; (13) reward-driven; (14) simulating and (15) social. This framework identifies which of these attributes prompt deep engagement, representing those that simultaneously produce cognitive, emotional and behavioural engagement [37]. According to these authors, pro-environmental engagement through games is achieved by experiential learning and with powerful narratives. The information should be concrete and credible to connect with people's experience and values. An engaging experience should also be fun with challenges that include achievable goals. When these factors are associated with social interactions and peer pressure, there is more chance that behavioural change will occur.

3. The Board Game: *A Planet Near the Abyss*

As a proposal devoted to EfS, we designed and manufactured a board game intended to enhance undergraduate students' knowledge and understanding of GC and encourage pro-environmental student engagement [60]. In order to motivate people into action, the attributes proposed by Ouariachi et al. [59] were considered in the game design.

A cooperative board game design was used because we intended to enhance social interaction, because social elements in games constitute a major category for fostering affective and behavioural engagement [11]. Such collaborative mechanics should enable the occurrence of changes in attitude towards sustainability or the environment [61]. In addition, some studies have indicated that multiplayer role-plays seem to enable empowerment regarding environmental issues [62] and increase awareness of collaboration [63].

Many works propose experiential learning as a good model for EfS [59,64], therefore, *experiential learning* was pursued in the game design by affording hands-on experiences in a simulated context, providing different levels of abstraction and focusing on the features of GC, along with including moments for individual or group reflection. It goes without saying that we also sought to offer students an interesting and enjoyable experience.

The game proposed for GC education is called *A Planet Near the Abyss*, which was inspired by a commercial cooperative board game called *Forbidden Island* created by Matt Leacock and distributed by Devir Iberia and Gamewright®. Like *Forbidden Island*, our educational board game is designed for two to six players. Since it is a cooperative game, all the players comprise a team and if a member of the team loses, all the other members also lose and the game is over.

The *narrative-driven* approach is inspired by the *Forbidden Island* game, which may promote a deep student immersion in the game environment and thus increase their motivation [65]. The game involves 23 different ecosystems (Figure 1), some natural and others anthropic, each represented by a different tile. One side of the tile displays an image of the ecosystem, and the other side has an image of the same ecosystem that is affected by GC. The tiles that reflect the ecosystems affected by GC show shocking images for provoking *meaningful*, emotions, which could influence player motivation, attitudes and values [66,67]. The ecosystems were chosen for being currently affected by GC or for their vulnerability to be affected in the near future. Some examples of the natural ecosystems include coral reefs, mangrove forests, and Mediterranean forests. Additionally, we added anthropogenic ecosystems, such as London, Polynesia, and Norilsk. In these cases, both sides of the tiles are the same, because GC has already affected these ecosystems, and so it is not a prediction, as in the rest of the board tiles [68]. Players take turns moving their pieces around the board and movements on the board must be crosswise, never diagonal. A spaceship appears on the board and this is because the goal of the game is to rescue the four endangered animal species (African elephant, caribou, orangutan and Iberian lynx) within their corresponding ecosystems (savanna, tundra, jungle and Mediterranean forest), to travel to the space station on a rocket in order to safeguard these species, and to continue research on how to save the planet. In this way, the students would become the heroes that save the planet, with meaningful feelings such as *efficacy-enhancement* or confidence for an increasing sense of empowerment to act [11,59]. The purpose of our game is to create inspiring characters as a powerful strategy to achieve an emotional connection, since such characters can reflect the human aspects of GC. Therefore, the aim is to create *identity-driven* qualities that emerge when connections are made between the game and the personal experiences of the players.

The game has two packs of cards, one for conservation and one for impact. Each impact card explains how GC affects a given ecosystem and implies that the ecosystem tile has to be turned around towards the side affected by the GC. The conservation cards consist of seven Species cards, four Habitat Protection cards, three Escaping by Spaceship cards, and five Ecologist cards (Figure 2). The Species cards allow players to save endangered species. The Habitat Protection cards allow ecosystem tiles to be restored by turning them to the side unaffected by GC. The Space Escape cards allow players to escape the planet once they have saved the four endangered animal species. The cards for the ecologists ask questions or pose challenges regarding the GC that the students must resolve by working together. The questions or challenges set out on these cards require reflective work from the students while enhancing their GC knowledge. In addition, there needs to be agreement on which player rescues which endangered species, depending on their position on the board. We have included 10 Ecologist cards: two cards for each component of GC. The Ecologist cards aim to improve understanding of environmental issues. These cards address issues such as the effect of anthropogenic factors on biodiversity conservation, biochemical cycles and their relation to ecological successions, air pollution, human-induced climate change, and overpopulation and its consequences (deforestation, fires and overexploitation). *Concrete and credible* information is integrated into the game mechanics through impact cards, avoiding extensive and complex analyses. It has been our objective to offer challenges with achievable goals, as proposed by Waddington and Fennewald [69]. These authors demonstrated that affective issues, including induced fatalism, can be provoked through making challenges in games extremely difficult, which reduces student motivation and engagement. Challenges are designed for the consequences of decisions, and the actions taken in the game represent the feedback players receive and replicate in real life, so this feedback should be positive and encouraging [59]. Thus, the challenges in our game would be considered *feedback oriented*.

Over the course of the game, cards are drawn in each turn: two from the conservation pack and either three or one from the impact pack (if the players' answer to the Ecologists' card is correct). When the same impact card comes up twice during the game, the ecosystem tile is removed from the board and players lose mobility. If this happens on the ecosystem tiles where endangered species live, or on the spaceship tile, then the players lose the game. An endangered species can be saved if a player obtains four cards for that species and locates those cards in the ecosystem where the species lives or in adjacent tiles. The game has a risk marker, which shows the degree of harm caused by GC. The risk increases whenever a player receives a card for an ecologist. If the players reach the top of the risk marker and they have been unable to save all endangered species, they lose.

The game, *A Planet Near the Abyss*, has three levels: beginner, medium, and advanced. The different levels provide suitable changes to connect to the prior knowledge of young people and, hence, the game is *challenging* with different tasks that require effort to perform. Therefore, the students can become aware of the consequences that their actions have for our planet, and this can induce them to reflect on how our lifestyles can affect the environment. In addition, players would be able to replay the levels to practice their skills before moving on to the more difficult levels [70]. Levelling is also important for motivating behavioural change because people can feel safer and closer to their goal than they might have expected [71].

To facilitate the explanation of the instructions, we developed a video tutorial that places students in the game context and indicates the goal to achieve in order to win the game, as well as the steps required to be undertaken (https://youtu.be/Q6jnZXIEYTw, accessed on 26 October 2021).

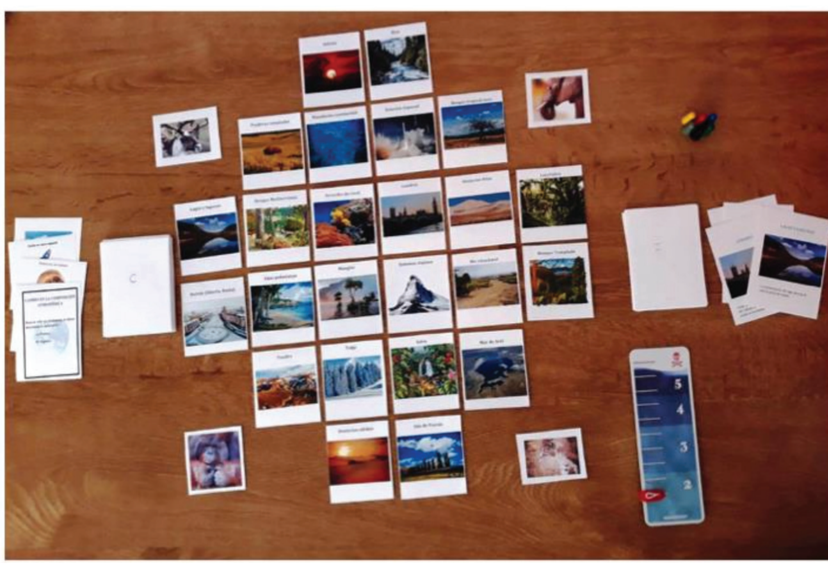


Figure 1. *A Planet Near the Abyss* board game. The board, representing the planet Earth, is composed of 23 ecosystems affected by global change, each represented by a different tile.

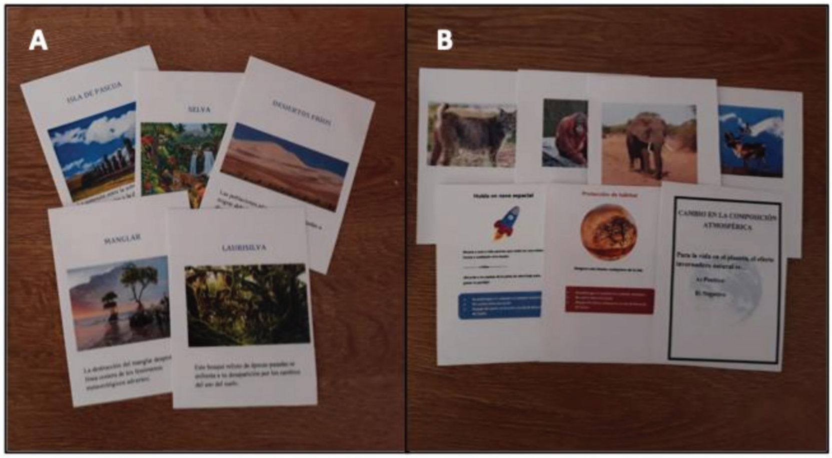


Figure 2. Packs of cards of the game, *A Planet Near the Abyss*. (**A**) Impact cards explain how global change affects a given ecosystem; (**B**) Conservation cards: 7 Species cards, 4 Habitat Protection cards, 3 Escaping by Spaceship cards, and 5 Ecologist cards.

4. Materials and Methods

4.1. Study Participants and Procedure

The board game, *A Planet Near the Abyss*, previously designed by the Authors [60], was validated, implemented, and evaluated in two phases:

- Phase I (validation phase), in which different aspects of the game were evaluated by 6 volunteers (4 women and 2 men between the ages of 26 and 28), who were students of the Master's Degree in Secondary Education (K-12) (Biology–Geology specialty), a demanding programme requiring high grades for admittance. These participants were considered experts and qualified evaluators of the educational game, since they were science graduates who, as future secondary teachers, had shown high performance and strong motivation in EfS. In addition, their ages and the cultural context in which they had been educated were closer to those of the potential users of the game. This could be relevant to a proper appraisal of the playability of the game by the current students. The feedback generated during this phase improved the game design and playing rules.
- Phase II (implementation–evaluation phase), in which the game was implemented with 128 students of the Bachelor's Degree in Primary Education (K-6) (90 women and 38 men between the ages of 20 and 25). This study formed part of the Science Education subject of the third course in the degree. The students were split into four groups of approximately thirty-two each. Four tutors were present in the classroom and they acted as guides during the game. After the students played the educational board game for 2 h in a classroom, the learning performance, dimensions of engagement [37], and engagement regarding climate-change-related issues through serious gameplay [59] were evaluated. These participants were considered potential users of the board game, being future primary school teachers interested in broadening their knowledge concerning environmental issues.

4.2. Analysis of the Validation Phase

After playing the educational game, the Master's students filled out a questionnaire that evaluated the usability of the game and analysed its communicative and educational elements through items with multiple answers and open questions.

The items for the evaluation of usability were chosen based on the questionnaire, "System Usability Scale" (SUS) [72], to evaluate usability and functionality. This questionnaire was made up of 4-scale Likert items valued from 1 to 4 (1 = "strongly disagree", 2 = "disagree", 3 = "agree" and 4 = "strongly agree"), and two open questions to gather opinions on how to improve the usability and strengths of the game. An even number of scales in the Likert questionnaire was chosen in order to avoid unnecessary neutral responses [73,74].

As a means of evaluating the communicative and educational aspects of the game, the dimension proposed by [75] was adapted, selecting the criteria that fit our game. Three dimensions were evaluated: 6 items were prepared to evaluate the Gameplay dimension (number of players, type of game, duration, dynamic, objective and entertaining); 3 items concerned the Contents dimension (relevant, story and terminology); and 2 other items served to assess the Educational dimension (competence development and skills). The items were valued according to the Likert scale (from 1 "strongly disagree" to 4 "strongly agree") and at the end of each aspect an open question was asked to gather proposals for improvement. A general rating scale from 1–10 was used for a question to determine the overall assessment of the game. Another question asked whether the participants would use the game as teaching material in their classes, with a possible answer between three options, "Yes", "No", and "Maybe", and there was a final open question to establish their general opinion of the game.

4.3. Analysis of the Implementation–Evaluation Phase

The authors used a short qualitative survey to explore the learning performance and student engagement from students of the Bachelor's Degree in Primary Education after playing a GC game. Thematic analysis [76,77] was used on data collected through open questions. Examples of students´ answers were translated from Spanish to English. These answers, containing information vital to this research project, are compiled in the Results section. Reliability of the data analysis was assessed twice according to procedure, i.e., following the pilot and the main phase of the analysis [77]. For the main phase, the intra-dimension reliability was 80%, where the students' answers were coded at two points in time.

The learning performance about GC was evaluated through two pre-test and post-test open questions:

Q1. "What is GC and what consequences does it have?"

Q2. "Do you think that something you do affects GC? If so, indicate what."

The data compiled in the first question were structured into main categories or dimensions, most of which were based on preconceived subjects related to existing knowledge concerning GC. In this sense, we categorized the students' answers according to the definition of GC, as a "set of environmental changes affected by human activity, with particular reference to changes in the processes that determine the functioning of the Earth system " [10] (p.23), and we also used their five components as categories. Therefore, the students' ideas were categorized and quantified in relation to GC: (1) environmental changes; (2) human activity; (3) Earth system disturbance; (4) changes in atmospheric composition; (5) climate change; (6) changes in biogeochemical cycles; (7) land-use changes; and (8) biodiversity changes, in addition to some categories identified from the data, such as (9) positive changes and (10) other changes (Figure 3). Each student response was classified into different categories and the percentages of the categories were calculated, taking into account the number of students (128).

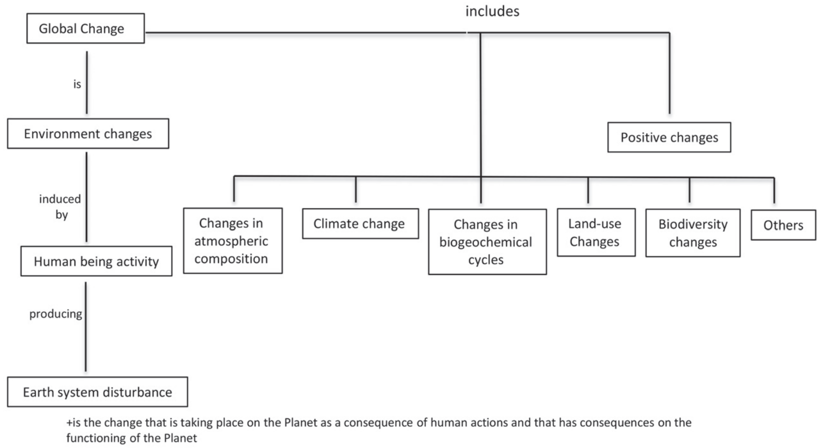


Figure 3. Scheme used to determine categories in the question: What is global change and what consequences does it have? Source: adapted from Duarte et al. [10].

In the second question, ideas concerning the activities that contribute to the GC were classified into categories and items, where the categories were inferred from the data, and finally quantified taking into account the number of students (128). According to the students' answers, the categories established based on the responses to this question involved: (1) plastic use; (2) paper use; (3) car use; (4) non-renewable energies; (5) gas production; (6) water waste; (7) throw-away items; (8) meat consumption; (9) failure to recycle; (10) forest burning; (11) natural-resource exploitation; (12) textile use; and (13) deforestation.

In order to explore student engagement, after finishing the game, the students answered one open-ended question regarding their general opinion of its value. This question was deliberately open-ended to encourage the students to reflect on both what was learned and the learning process itself. The answers from the students regarding the quality of their learning experience allowed for the determination of the indicators of engagement [11,78]. This survey asked:

Q3. What was your experience of playing the *A Planet Near the Abyss* game?

Initially, students' comments on the game played for both learning and entertainment were used to explore the students' learning experiences. For this analysis, we used core words related to learning (e.g., "educational", "insightful" and "informative") and entertainment (e.g., "fun", "enjoyable").

To assess the strength of the student engagement, we used the dimensions of engagement framework, based on Lorenzoni et al. [37], for climate change. In our case, we related these dimensions to GC. The players' feedback that indicated their reaction to or feeling towards the game, was categorized as "cognitive involvement", "emotional involvement" or "behavioural involvement", which were taken to reflect engagement, as suggested by Lorenzoni et al. [37]. Based on these authors, we defined these categories as:

- Cognitive involvement: what people know or think about GC, and how much mental effort they are willing to expend to understand it.
- Emotional involvement: what and how strongly people feel about GC.
- Behavioural involvement: what and how much people do to address GC.

Finally, the game performance was established against the framework of engagement regarding climate-change-related issues through serious gaming [59]. The framework encompasses 15 main attributes that would make the most impact on user engagement at the cognitive, emotional, and behavioural levels. The results of the students' learning experience were compared with these attributes, establishing the engagement value of the game.

5. Results

5.1. Validation Phase

The answers of the questionnaires filled out by the future secondary teachers (Figure 4) were analysed in a quantitative manner and some statistical parameters (mean and variance) were calculated. Figure 4 shows that the future teachers encountered difficulties in understanding the instructions and had to return to them or ask for help while playing. Despite this, they claimed that playing the game was easy. In general, the gameplay was evaluated positively. These evaluators agreed that the number of players, the type of game, the duration of the game, and its purpose were adequate, while the dynamics of the game were assessed as inappropriate due to the disagreement of the participants over some of the rules. The majority considered the game entertaining and valued the contents of the game very positively. According to these future teachers, the game develops key competencies, as well as skills related to environmental issues. The overall assessment mean of the game was six and the majority of the future teachers declared that maybe they would use this resource.

After analysing the results of the questionnaires and taking into account the opinions of the evaluators and their proposals, we made certain changes in the game to improve the instructions and its dynamics.

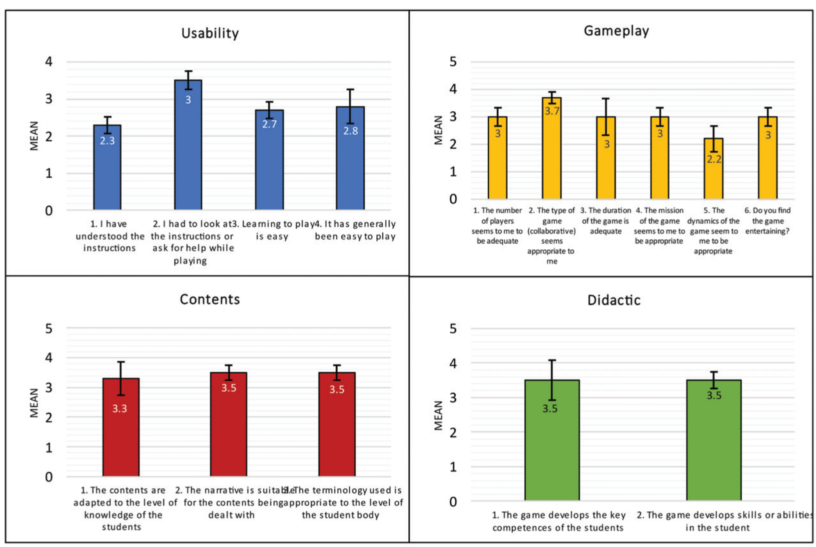


Figure 4. Evaluation of usability and communicative and educational elements of the game (adapted from Ouariachi et al. [75]).

5.2. Users' Learning Performance

Figure 5 lists the categories and their frequencies used in the analysis in the question, Q1: "What is GC and what consequences does it have?". In the pre-test, most students (50%) considered causes of GC to be induced by humans through pollution, the destruction of the ozone layer, and the greenhouse effect, leading to global warming. In this sense, the answers obtained expressed that GC is the transformation the planet is undergoing due to the actions of human beings. Its consequences are the destruction of the ozone layer, temperature changes, the greenhouse effect, and the melting of the poles (Participant 66).

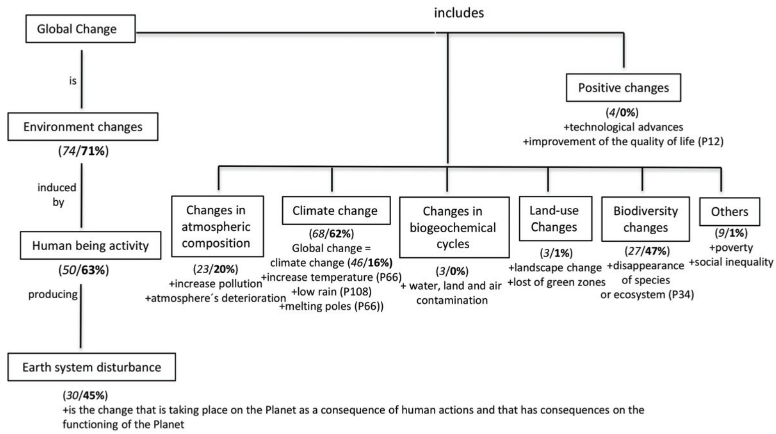


Figure 5. Scheme used to determine categories in the question: What is global change and what consequences does it have? Examples are marked by a "+" and they are related to the participant number (P). The category frequencies in pre-test (in *italics*) and post-test (in bold), are respectively shown in terms of percentage. Source: adapted from Duarte et al. [10].

Many students (46%) confused GC with climate change or were only able to establish a relationship with this factor. Mostly, the consequences they named were the thawing of the poles and the increase in Earth's temperature. Examples of these answers indicated that GC is the process by which weather changes abruptly, for example, when in the winter season we might find very high temperatures. The consequences are usually droughts, insufficient rain or excess rain, tidal waves, and floods (Participant 108).

A few students (4%) confused GC with globalization and/or described it as a change that has negative and positive consequences, such as technological advances. In this way, some students thought that GC encompasses all those changes that occur on the planet due to human intervention. As far as the consequences are concerned, students were able to draw both positive and negative conclusions. Negative: deterioration of the land and the atmosphere or positive: improvement of quality of life (Participant 12).

After playing, some participants (16%) still defined GC as climate change and did not relate it to the other factors. However, there was an increase in student users of the game (63%) who added human activity to their definition, recognizing that it is an environmental change related to the loss of biodiversity and/or the destruction of ecosystems (47%). Some students responded that GC is the actions that human beings perform, and which affect the entire world. They thought that these included consequences such as the disappearance of some species or ecosystems (Participant 34).

The students who did not know how to define GC or who defined it as something positive before using the game, afterwards gained a clear idea that the consequences of this change are negative. Changes in biogeochemical cycles and land use were practically ignored by the students, while they cited changes in atmospheric composition and climate change with a similar frequency in the pre and post-test phases.

Table 1 shows the frequencies of the categories and items determined from the answers to the question, Q2: "Do you think that something you do affects GC? If yes, indicate what." Some students appeared to find it difficult to recognize that their daily activities could affect GC while others instead described actions in favour of the environment such as recycling or saving water. In the pre-test, some students (54%) recognized that they used the car when they could use public transportation or other means that do not pollute and/or they did not recycle (32%). After playing the game, students recognized that some of their daily activities increased GC, mainly the use of a car (68%), or failure to recycle (42%); however, they cited the use of non-renewable energy and the use of plastics with similar a frequency in the pre-test and post-test. Only the water waste category decreased significantly after the game. To a lesser extent, a few students mentioned other potentially harmful personal actions, such as meat consumption or textile use and cited general problems such as burning forests.

Table 1. Frequencies of the categories or items determined in the question: Do you think that something you do has to do with Global Change? If yes, indicate what".

Category/Items	Pre-Test (%)	Post-Test (%)
Plastic use	17	15
Paper use	4	1
Car use	54	68
Non-renewable energies use	24	21
Gas production	14	14
Waste water	21	11
Throw away waste	17	11
Consumption of meat	1	2
Do not recycle	32	42
Forest burning	0	1
Natural resource use	5	4
Textile use	1	2
Deforestation	2	0

5.3. User Experience of Playing and Engagement

The participants' responses indicated that the majority of the student users of the game considered, *A Planet Near the Abyss*, both educational and entertaining. In fact, the feedback of 95% of the students revealed engagement in learning and 68% thought that the game was entertaining. The students commented that they learned very important things about the Earth and became aware of the danger that our actions have for our planet through the game in a fun and interesting way (Participant 10).

In their responses, many students (55%) used educational as well as entertaining core words (fun, entertaining, dynamic, educative, didactic, educational). The students acknowledged that the game is quite good, being both educational and entertaining, so that they were playing and learning at the same time (Participant 90).

The results in this research indicate that a majority of the students (66%) felt that their thinking was stimulated during playing the game. Student responses suggest that through this game, the students were engaged cognitively with game-based learning. The participants recognized that the game helped them to understand the importance of protecting the ecosystems of our planet to save species. They also commented that the game is very ingenious and original, and full of meaning and information (Participant 67).

Emotional responses were detected in 34% of the students using the game, indicating that a significant percentage of the students were emotionally engaged. The students indicated that the game raised awareness of damaged ecosystems because the affected board cards show how damage makes the world ugly and that it opened their eyes to the seriousness of the issue (Participant 100).

A few students (24%) showed behavioural engagement. They recognized that the need for collaboration between all players in order to save the planet in the game, represents a parallel to reality since that is what we are trying to achieve in our real world (Participant 34).

6. Discussion

The research findings were further assessed against a framework of climate change engagement through serious games [59], relating the students' answers to established attributes proven to prompt deep engagement (Figure 6).

In the first instance, our game poses *achievable challenges*. The challenges presented to players in our game, as well as the behavioural change promoted in the messages, are within reach of the players, as proposed by Waddington and Fennewald [69]. The results after the game was finished indicated that the players performed well during the game and that they felt good after resolving difficult tasks, thereby attaining the goal of the game. Therefore, the game is *challenging*. They commented that the game foments deep learning about GC. In fact, after playing, most students added human activity to their definition of GC. They recognized that it is an environmental change and that it began partly as a consequence of the loss of biodiversity and/or the destruction of ecosystems.

In terms of behaviour, our game encourages behaviour-specific changes that are possible and easy to undertake in the real world. The players remarked that collaboration, of the type this game inculcates, is a critical issue for mitigating GC. In this sense, studies have also shown that one of the greatest barriers to pro-environmental behaviour is a sense that individual efforts are insufficient to combat environmental crises such as climate change [79]. Consequently, some social movements are maturing, for example, the FridaysForFuture movement (FFF), where efforts are focused on promoting social change by going beyond the individual toward a collective agency [80], which is in accordance with this game's objective of cooperation.

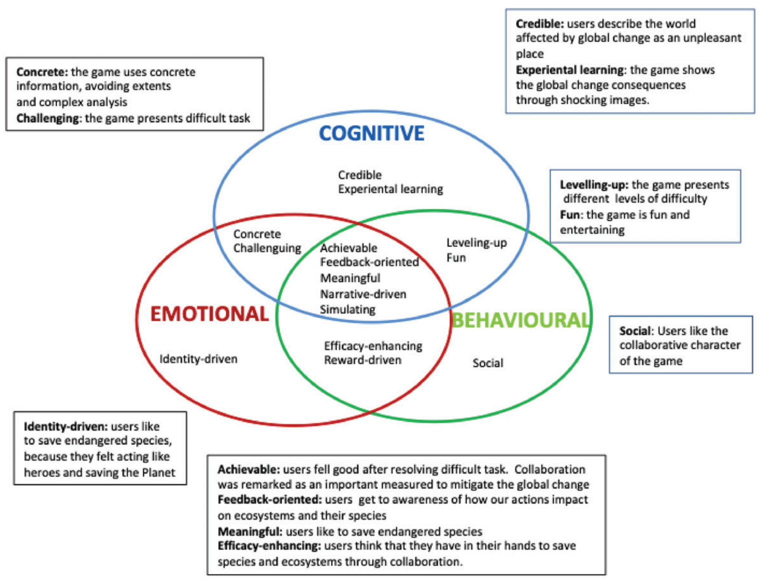


Figure 6. Students' experiences playing the game, *A Planet Near the Abyss*, mapped against a framework of climate change engagement through serious games. Source: adapted from Ouariachi et al. [59].

Moreover, after playing, our students expressed greater awareness about the environmental crisis; indicated also by an increase of awareness about the daily activities that they recognized as contributing to GC. Hence, their feelings of personal responsibility for the environment increased after playing, implying potential future pro-environmental behaviours. This result is consistent with those reported, for example, by Schroth et al. [81] which showed that through game, users increase their local responsibility for climate change issues.

The problem of GC can frequently leave people feeling powerless. The answers from the student users indicated that after playing they felt that we all have a certain power to save species and ecosystems through collaboration. Therefore, the game proved to be *efficacy enhancing* and promoted a feeling of empowerment.

People may often regard GC as an invisible problem, so to experience the problem is the best way to address it. The game presented here is based on experiential learning, since the *narrative-driven* aspect and design of the game show GC consequences through shocking images of different ecosystems which players must save before those habitats disappear.

Our game includes *concrete* and *credible* challenges, which are connected to the real life of students. Users remarked that the images show how the world could be after GC. They described this world as an unpleasant place, showing emotional pathways triggered by the game, therefore, according to the students, the game presents trustworthy information. In addition, the *A Planet Near the Abyss* game has a *levelling-up* quality by presenting different levels of difficulty (low, intermediate and advanced).

The consequences of decisions and actions taken in the game simulate the feedback that players receive and replicate in real life, and this feedback should be positive and encouraging [59]. Thus, the game's challenges are *feedback oriented*. The students enjoyed resolving the game challenges and they recognized that the game helped raise their awareness of how the actions of individuals can have an impact on ecosystems and their species.

Educational games, to be effective, should involve some degree of *entertainment and fun* [82]. Many students in our research showed in their answers that our educational game was fun and entertaining.

The images and the messages in games can provoke fear and concern, and these feelings need to be counterbalanced with hopeful feelings. Therefore, games can provoke *meaningful* emotions about GC. Moreover, games should appeal to players' identities—not only to the people they are right now, but also to the people they would like to become [71]. In this sense, many students stated that they enjoyed saving the endangered species, because they felt as though they were acting like heroes and saving the planet. Thus, our game can trigger emotional responses in its players.

The *social element* is present in our game in its cooperative character. Many students enjoyed the cooperative nature of the game instead of competitive strategies. In this sense, feeling the recognition of and gaining a sense of belonging to a group, could be facilitated by the cooperative character of the game, allowing for the development of intrinsic motivations [42].

The attributes present in our game, such as its being achievable, feedback oriented, meaningful, and narrative driven can be seen as valuable for increasing the potential to engage participants at the cognitive, emotional, and behavioural levels simultaneously (Figure 6), in agreement with Ouariachi et al. [59]. Moreover, these authors have indicated that the more attributes are involved in the design of a game, the stronger physical and mental connections it builds with participants, and the greater the potential will be to influence human behaviour.

7. Conclusions

Users' learning outcomes demonstrated that our game improved the understanding of the consequence of human activity, such as biodiversity loss and ecosystem destruction. In addition, the findings indicate that playing can promote a sense of personal responsibility for the environment. In this sense, the students in their responses indicated a pronounced increase in this feeling of responsibility, particularly in relation to car use and recycling, indicating potential pro-environmental behaviour.

Players developed strong emotional, cognitive, and behavioural engagement. The game prompted emotional engagement, where a balance between positive and negative sentiments promoted a feeling of empowerment. The cognitive engagement that was generated sharpened the students' awareness of human activity as a major driver of GC. Behavioural engagement was also fomented, since cooperation, one characteristic of the board game, was recognized as key to mitigate GC, leading to a behavioural change in the participants.

Our game presents numerous attributes related to the engagement framework proposed by Ouariachi et al. [59]. These attributes are achievable, concrete, credible, challenging, fun, meaningful, social, efficacy enhancing, narrative-driven, feedback oriented, and identity-driven, offering experiential learning in a levelling-up context. These attributes are related to developing engagement at the cognitive, emotional, and behavioural levels. Therefore, the proposed game has a strong potential to influence human behaviour. Thus, our results reaffirm the value of games for educators.

Regarding the limitations of this work, we recognize that it is a small-scale study conducted over a short period. Therefore, a long-term experiment would be helpful to compile follow-up data needed to assess the impact of behavioural shifts over time [11]. More time to play in combination with greater exposure to the board-game context could also have multiplied the learning impact [22], given primarily that a key goal of our game is to promote the understanding of a complex phenomenon comprising GC causes, impacts, and possible actions. Another limitation involves the low frequency of the answers of the students regarding "water waste", "meat consumption" and "textile use" and some GC components (e.g., biogeochemical cycles changes and land use changes). This low incidence rate could be related to the small number of challenges related to these issues within the game, constituting a weakness in its design.

Author Contributions: Conceptualization, M.V.-V., D.G.-R., B.P.-F. and A.F.-O.; Data curation, M.V.-V. and D.G.-R.; Formal analysis, M.V.-V., D.G.-R. and A.F.-O.; Methodology, M.V.-V. and A.F.-O.; Resources, M.V.-V. and A.F.-O.; Supervision, M.V.-V. and A.F.-O.; Visualization, M.V.-V. and A.F.-O.; Writing—original draft, M.V.-V., D.G.-R., B.P.-F. and A.F.-O.; Writing—review & editing, M.V.-V. and A.F.-O. Project administration, M.V.-V. and A.F.-O. Funding acquisition, M.V.-V. and A.F.-O. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by University of Granada, grant numbers PPJI2018-06, PID 18-363 and PBID-19-67, and Junta de Andalucía (Spain), research group HUM-613.

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

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. The data are not publicly available due to privacy.

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

References

1. Oliver, M.C.; Adkins, M.J. "Hot-headed" students? Scientific literacy, perceptions and awareness of climate change in 15-year olds across 54 countries. *Energy Res. Soc. Sci* **2020**, *70*, 101641. [CrossRef]
2. Jaén, M.; Barbudo, P. Evolución de las percepciones medioambientales de los alumnos de educación secundaria en un curso académico. *REurEDC* **2010**, *7*, 247–259. [CrossRef]
3. Hines, J.M.; Hungerford, H.R.; Tomera, A.N. Analysis and Synthesis of Research on Responsible Environmental Responsible Behavior: A Meta-Analysis. *J. Environ. Educ.* **1986**, *18*, 1–8. [CrossRef]
4. Bamberg, S. Changing environmentally harmful behaviors: A stage model of self-regulated behavioral change. *J. Environ. Psychol.* **2013**, *34*, 151–159. [CrossRef]
5. Hunecke, M.; Blöbaum, A.; Matthies, E.; Höger, R. Responsibility and environment: Ecological norm orientation and external factors in the domain of travel mode choice behavior. *Environ Behav.* **2001**, *33*, 830–852. [CrossRef]
6. Cottrell, S.P.; Meisel, C. Predictors of personal responsibility to protect the marine environment among scuba divers. In Proceedings of the Northeastern Recreation Research Symposium, New York, USA, 6–8 April 2003; pp. 252–261.
7. Falkenberg, T.; Babiuk, G. The status of education for sustainability in initial teacher education programmes: A Canadian case study. *Int. J. Sustain. High. Educ.* **2014**, *15*, 418–430. [CrossRef]
8. Sureda-Negre, J.; Oliver-Trobat, M.; Catalan-Fernández, A.; Comas-Forgas, R. Environmental education for sustainability in the curriculum of primary teacher training in Spain. *Int. Res. Geogr. Environ. Educ.* **2014**, *23*, 281–293. [CrossRef]
9. Cook, R.; Cutting, R.; Summers, D. If Sustainability Needs New Values, Whose Values? Initial Teacher Training and the Transition to sustainability. In *Sustainability Education: Perspectives and Practice across Higher Education*; Jones, P., Selby, D., Sterling, S., Eds.; Earthscan: New York, NY, USA, 2010; pp. 313–327.

10. Duarte, C.M.; Abanades, J.C.; Agustí, S.; Alonso, S.; Benito, G.; Ciscar, J.C.; Valladares, C.F. *Cambio Global. Impacto de la Actividad Humana Sobre El Sistema Tierra*; Consejo Superior de Investigaciones Científicas (CSIC): Madrid, Spain, 2006.
11. Fernández-Galeote, D.; Rajanen, M.; Rajanen, D.; Legaki, N.Z.; Langley, D.J.; Hamari, J. Gamification for climate change engagement: Review of corpus and future agenda. *Environ. Res. Lett.* **2021**, *16*, 063004. [CrossRef]
12. Bakhuys-Roozeboom, M.; Visschedijk, G.; Oprins, E. The effectiveness of three serious games measuring generic learning features. *Br. J. Educ. Technol.* **2015**, *48*, 83–100. [CrossRef]
13. Di Bitonto, P.; Roselli, T.; Rossano, V.; Frezza, E.; Piccinno, E. An educational game to learn type 1 diabetes management. In Proceedings of the 18th International Conference on Distributed Multimedia Systems, Miami, FL, USA, 9–11 August 2012; pp. 139–143.
14. Shaffer, D.W. *How Computer Games Help Children Learn*; Palgrave Macmillan: New York, NY, USA, 2006.
15. Gee, J.P. What video games have to teach us about learning and literacy. *Comput. Entert.* **2003**, *1*, 20. [CrossRef]
16. Stokes, L.C.; Selin, N.E. The Mercury Game: Evaluating a Negotiation Simulation that Teaches Students About Science-Policy Interactions. *J. Environ. Stud. Sci.* **2014**, *6*, 597–605. [CrossRef]
17. Harker-Schuch, I.E.; Mills, F.P.; Lade, S.J.; Colvin, R.M. CO_2peration–Structuring a 3D interactive digital game to improve climate literacy in the 12-13-year-old age group. *Comput. Educ.* **2020**, *144*, 103705. [CrossRef]
18. Girard, C.; Ecalle, J.; Magnan, A. Serious games as new educational tools: How effective are they? A meta-analysis of recent studies. *J. Comput. Assist. Learn.* **2013**, *29*, 207–219. [CrossRef]
19. Bellotti, F.; Kapralos, B.; Lee, K.; Moreno-Ger, P.; Berta, R. Assessment in and of serious games: An overview. *Adv. Hum. Comput. Interac* **2013**, *2013*, 136864. [CrossRef]
20. Gatti, L.; Ulrich, M.; Seele, P. Education for sustainable development through business simulation games: An exploratory study of sustainability gamification and its effects on students' learning outcomes. *J. Clean. Prod.* **2019**, *207*, 667–678. [CrossRef]
21. Plass, J.; Homer, B.; Kinzer, C. Foundations of game-based learning. *Educ. Psychol.* **2015**, *50*, 258–283. [CrossRef]
22. Wouters, P.; van Nimwegen, C.; van Oostendorp, H.; van der Spek, E.D. A metaanalysis of the cognitive and motivational effects of serious games. *J. Educ. Psychol.* **2013**, *105*, 249–265. [CrossRef]
23. Young, M.; Slota, S.; Cutter, A.; Jalette, G.; Mullin, G.; Lai, B.; Simeoni, Z.; Tran, M.; Yukhymenko, M. Our princess is in another castle: A review of trends in serious gaming for education. *Rev. Educ. Res.* **2012**, *82*, 61–89. [CrossRef]
24. Fabricatore, C.; Lopez, X. Sustainability learning through gaming: An exploratory study. *Electron. J. E-Learn.* **2012**, *10*, 209.
25. Nurmi, J.; Knittle, K.; Ginchev, T.; Khattak, F.; Helf, C.; Zwickl, P.; Castellano-Tejedor, C.; Lusilla-Palacios, P.; Costa-Requena, J.; Ravaja, N.; et al. Engaging Users in the Behavior Change Process with Digitalized Motivational Interviewing and Gamification: Development and Feasibility Testing of the Precious. *JMIR Mhealth Uhealth* **2020**, *8*, e12884. [CrossRef]
26. Lizzio, A.; Wilson, K. Feedback on assessment: Students "perceptions of quality and effectiveness". *Assess. Eval. High. Educ.* **2008**, *33*, 263–275. [CrossRef]
27. Trigueros, R.; Aguilar-Parra, J.M.; Lopez-Liria, R.; Cangas, A.J.; González, J.J.; Álvarez, J.F. The Role of Perception of Support in the Classroom on the Students' Motivation and Emotions: The Impact on Metacognition Strategies and Academic Performance in Math and English Classes. *Front. Psychol.* **2019**, *10*, 2794. [CrossRef] [PubMed]
28. Cooper, S.; Treuille, A.; Barbero, J.; Leaver-Fay, A.; Tuite, K.; Khatib, F.; Snyder, A.; Beenen, M.; Salesin, D.; Baker, D.; et al. The challenge of designing scientific discovery games. In Proceedings of the Fifth International Conference on the Foundations of Digital Games, Monterey, CA, USA, 19–21 June 2010; pp. 40–47.
29. Csikszentmihalyi, M. *Flow: The Psychology of Optimal Experience*; Harper Row: New York, NY, USA, 1991.
30. Brown, E.; Cairns, P. A Grounded Investigation of Game Immersion. In Proceedings of the Conference on Human Factors in Computing Systems of Vienna, Vienna, Austria, 24–29 April 2004; pp. 1297–1300.
31. Yee, N. Motivations for Play in Online Games. *Cyberpsychol. Behav.* **2006**, *9*, 772–775. [CrossRef] [PubMed]
32. Jimerson, S.R.; Campos, E.; Greif, J.L. Toward an understanding of definitions and measures of school engagement and related terms. *Calif. School Psychol.* **2003**, *8*, 7–27. [CrossRef]
33. Lan, X.; Ponitz, C.C.; Miller, K.F.; Li, S.; Cortina, K.; Perry, M.; Fang, G. Keeping their attention: Classroom practices associated with behavioral engagement in first grade mathematics classes in China and the United States. *Early Child Res. Q* **2009**, *24*, 198–211. [CrossRef]
34. Skinner, E.A.; Belmont, M.J. Motivation in the classroom: Reciprocal effect of teacher behavior and student engagement across the school year. *J. Educ. Psychol.* **1993**, *85*, 571–581. [CrossRef]
35. Newmann, F.M. *Student Engagement and Achievement in American Secondary Schools*; Teachers College Press: New York, NY, USA, 1992.
36. Connell, J.P.; Wellborn, J.G. Competence, autonomy, and relatedness: A motivational analysis of self-system processes. In *The Minnesota Symposia on Child Psychology*; Gunnar, M.R., Sroufe, L.A., Eds.; Lawrence Erlbaum Associates Inc.: Hillsdale, NJ, USA, 1991; Volume 23, pp. 43–77.
37. Lorenzoni, I.; Nicholson-Cole, S.; Whitmarsh, L. Barriers Perceived to Engaging with Climate Change among the UK Public and Their Policy Implications. *Glob. Environ. Chang.* **2007**, *17*, 445–459. [CrossRef]

38. Mattheiss, M.D.; Kickmeier-Rust, C.M.; Steiner, D.A. Motivation in game-based learning: It's more than 'flow'. In *Lernen im Digitalen Zeitalter, Proceedings of the Workshop-Band Dokumentation der Pre-Conference zur DeLFI2009—Die 7. E-Learning Fachtagung Informatik der Gesellschaft für Informatik e.V., Berlin, Germany, 14-17 September 2009*; Schwill, A., Apostolopoulos, N., Eds.; Logos Verlag: Berlin, Germany, 2009; pp. 77–84.
39. Shu, L. Student Engagement in Game-Based Learning: A Literature Review. Master's Thesis, The University of Texas at Austin, Austin, TX, USA, 2018; p. 53.
40. Buckley, P.; Doyle, E. Gamification and student motivation. *Interact. Learn. Environ.* **2016**, *24*, 1162–1175. [CrossRef]
41. Fischer, C.; Malycha, C.; Schafmann, E. The Influence of Intrinsic Motivation and Synergistic Extrinsic Motivators on Creativity and Innovation. *Front. Psychol.* **2019**, *10*, 137. [CrossRef]
42. Mahmud, S.N.D.; Husnin, H.; Tuan Soh, T.M. Teaching Presence in Online Gamified Education for Sustainability Learning. *Sustainability* **2020**, *12*, 3801. [CrossRef]
43. Broer, J.; Breiter, A. Potentials of Gamification in Learning Management Systems: A Qualitative Evaluation. In *Design for Teaching and Learning in a Networked World*; Conole, G., Klobučar, T., Rensing, C., Konert, J., Lavoué, E., Eds.; EC-TEL, Lecture Notes in Computer Science; Springer: Cham, Germany, 2015; Volume 9307, pp. 389–394. [CrossRef]
44. Ekici, M. A systematic review of the use of gamification in flipped learning. *Educ. Inf. Technol.* **2021**, *6*, 3327–3346. [CrossRef]
45. Kan, B.; Tan, S. Interactive Games: Intrinsic and Extrinsic Motivation, Achievement, and Satisfaction. *J. Manag. Strategy* **2014**, *5*, 110–116.
46. Tsai, J.C.; Liu, S.Y.; Chang, C.Y.; Chen, S.Y. Using a Board Game to Teach about Sustainable Development. *Sustainability* **2021**, *13*, 4942. [CrossRef]
47. Tsai, J.C.; Cheng, P.H.; Liu, S.Y.; Chang, C.Y. Using board games to teach socioscientific issues on biological conservation andeconomic development in Taiwan. *J. Balt. Sci. Educ.* **2019**, *18*, 634–645. [CrossRef]
48. Flood, S.; Cradock-Henry, N.A.; Blackett, P.; Edwards, P. Adaptive and interactive climate futures: Systematic review of 'serious games' for engagement and decision-making. *Environ. Res. Lett.* **2018**, *13*, 063005. [CrossRef]
49. Rajanen, D.; Rajanen, M. Climate change gamification: A literature review. In Proceedings of the GamiFIN 2019 Conference, Levi, Finland, 8–10 April 2019; pp. 253–264. Available online: http://ceur-ws.org/Vol-2359/paper22.pdf (accessed on 26 October 2021).
50. Powell, K.C.; Kalina, C. Cognitive and social constructivism: Developing tools for an effective classroom. *Education* **2009**, *130*, 241–250.
51. Monroe, M.C.; Plate, R.R.; Oxarart, A.; Bowers, A.; Chaves, W.A. Identifying effective climate change education strategies: A systematic review of the research. *Environ. Educ. Res.* **2017**, *25*, 791–812. [CrossRef]
52. Eisenack, K. A climate change board game for interdisciplinary communication and education. *Simul. Gaming* **2013**, *44*, 328–348. [CrossRef]
53. Cheng, P.H.; Tsai, J.C.; Chen, S.Y.; Chang, C.Y. Learning transfer to daily habit: The design and effectiveness of water resources board Game. *J. Environ. Educ. Res.* **2020**, *16*, 1–36.
54. Cheng, P.H.; Yeh, T.K.; Tsai, J.C.; Lin, C.R.; Chang, C.Y. Development of an Issue-Situation-Based Board Game: A Systemic Learning Environment for Water Resource Adaptation Education. *Sustainability* **2019**, *11*, 1341. [CrossRef]
55. Ozge-Arslan, H.; Moseley, C.; Cigdemoglu, C. Taking attention on environmental issues by an attractive educational game: Enviropoly. *Procedia Soc. Behav. Sci.* **2011**, *28*, 801–806. [CrossRef]
56. Martin, G.; Felten, B.; Duru, M. Forage rummy: A game to support the participatory design of adapted livestock systems. *Environ. Model. Softw.* **2011**, *26*, 1442–1453. [CrossRef]
57. Jiménez-Aleixandre, M.P.; Gallástegui-Otero, J.R. 'Let's Save Energy!': Incorporating an environmental education dimension in the teaching of energy. *Environ. Educ. Res.* **2006**, *1*, 75–83. [CrossRef]
58. Ouariachi, T.; Chin-Yen, L.; Elving, W. Gamification Approaches for Education and Engagement on Pro-Environmental Behaviors: Searching for Best Practices. *Sustainability* **2020**, *12*, 4565. [CrossRef]
59. Ouariachi, T.; Olvera-Lobo, M.D.; Gutiérrez-Pérez, J.; Maibach, E. A framework for climate change engagement through video games. *Environ. Educ. Res.* **2018**, *25*, 701–716. [CrossRef]
60. Pérez-Fernández, B. Un planeta en el abismo: Propuesta para la educación científica en bachillerato a través de un juego de mesa sobre el cambio global. Official University Master's Degree in Compulsory Secondary Education and Baccalaureate Teaching Staff, Professional Training and Language Teaching. University of Granada, 2019, p.59. Available online https://digibug.ugr.es/handle/10481/53824 (acceded on 23 October 2021).
61. Chappin, E.J.; Bijvoet, X.; Oei, A. Teaching sustainability to a broad audience through an entertainment game—The effect of catan: Oil springs. *J. Clean. Prod.* **2017**, *156*, 556–568. [CrossRef]
62. Rumore, D.; Schenk, T.; Susskind, L. Role-play simulations for climate change adaptation education and engagement. *Nat. Clim. Change* **2016**, *6*, 745–750. [CrossRef]
63. Onencan, A.M.; Enserink, B.; Van de Walle, B. Sustainability indicators: Monitoring cross-county water cooperation in the Nzoia river basin, Kenya. *Sustainability* **2019**, *11*, 560. [CrossRef]
64. Dieleman, H.; Huisingh, D. Games by which to learn and teach about sustainable development: Exploring the relevance of games and experiential learning for sustainability. *J. Clean. Prod.* **2006**, *14*, 837–847. [CrossRef]

65. Hamari, J.; Shernoff, D.J.; Rowe, E.; Coller, B.; Asbell-Clarke, J.; Edwards, T. Challenging games help students learn: An empirical study on engagement, flow and immersion in game-based learning. *Comput. Human Behav.* **2016**, *54*, 170–179. [CrossRef]
66. Squire, K. Video games in education. *Int. J. Intell. Games Simul.* **2003**, *2*, 49–62.
67. Salen, K.; Zimmerman, E. *Rules of Play: Game Design Fundamentals*; The MIT Press: Cambridge, MA, USA, 2004.
68. Pérez-Fernández, B.; Vázquez-Vílchez, M.; Fernández-Oliveras, A. A Proposal for Global-Change Education based on an educational board game: A Planet on the Abyss, ERPA International Congresses on Education 2019 (ERPA 2019). *SHS Web Conf.* **2019**, *66*, 01029.
69. Waddington, D.I.; Fennewald, T. Grim FATE: Learning about systems thinking in an in-depth climate change simulation. *Simul. Gaming* **2018**, *49*, 168–194. [CrossRef]
70. Morris, B.J.; Croker, S.; Zimmerman, C.; Gill, D.; Romig, C. Gaming Science: The "Gamification" of Scientific Thinking. *Front. Psychol.* **2013**, *4*, 607. [CrossRef]
71. Heath, C.; Heath, D. *Switch: How to Change Things When Change Is Hard*; Random House Busines, Broadway Books: New York, NY, USA, 2010.
72. Brooke, J. SUS: A quick and dirty usability scale. In *Usability Evaluation in Industry*; Jordan, P.W., Thomas, B., Weerdmeester, B.A., McClelland, I.L., Eds.; Taylor and Francis: London, UK, 1996; pp. 189–194.
73. Nemoto, T.; Beglar, D. Likert-scale questionnaires. In Proceedings of the JALT 2013 Conference Proceedings, Tokio, Japan, 12–15 November 2013; Nemoto, T., Beglar, D., Eds.; Japan Association for Language Teaching: Tokio, Japan, 2013; pp. 1–8.
74. Wolfe, E.W.; Smith, E.V., Jr. Instrument development tools and activities for measure validation using Rasch models: Part I—Instrument development tools. *J. Appl. Meas.* **2007**, *8*, 97–123.
75. Ouariachi, T.; Olvera-Lobo, M.D.; Gutiérrez-Pérez, J. Evaluación de juegos online para la enseñanza y aprendizaje del cambio climático. *Enseñanza De Las Cienc.* **2017**, *35*, 193–214. [CrossRef]
76. Braun, V.; Clarke, V. Using thematic analysis in psychology. *Qual. Res. Psycho.* **2006**, *3*, 77–101. [CrossRef]
77. Schreier, M. *Qualitative Content Analysis in Practice*; SAGE, EEUU: Los Angeles, CA, USA, 2012.
78. Emblen-Perry, K. Enhancing student engagement in business sustainability through games. *Int. J. Sustain. High. Educ.* **2018**, *19*, 858–876. [CrossRef]
79. Axon, S. "Keeping the ball rolling": Addressing the enablers of, and the barriers to, sustainable lifestyles. *J. Environ. Psychol.* **2017**, *52*, 11–25. [CrossRef]
80. Francesconi, D.; Symeonidis, V.; Agostini, E. FridaysForFuture as an Enactive Network: Collective Agency for the Transition Towards Sustainable Development. *Front. Educ.* **2021**, *6*, 636067. [CrossRef]
81. Schroth, O.; Angel, J.; Sheppard, S.; Dulic, A. Visual climate change communication: From iconography to locally framed 3D visualization. *Environ. Commun.* **2014**, *8*, 413–432. [CrossRef]
82. Yamada, F.M.; Ribeiro, T.; Pirani Ghilardi-Lopes, N. Assessment of the prototype of an educational game on climate change and its effects on marine and coastal ecosystems. *Rev. Bras. Inform. Educ.* **2019**, *27*, 1–31. [CrossRef]

education sciences

Article

How to Run Your Own Online Business: A Gamification Experience in ESL

Mª Ángeles Hernández-Prados *, Mª Luisa Belmonte and Juan Carlos Manzanares-Ruiz

Deptartment Teoría e Historia de la Educación, Universidad de Murcia, 30100 Murcia, Spain;
marialuisa.belmonte@um.es (M.L.B.); juancarlos.manzanaresr@um.es (J.C.M.-R.)
* Correspondence: mangeles@um.es

Abstract: Notwithstanding the importance and relevance of gamification as a topical methodology in education, and after a literature review, there are just a few studies using role-playing games. In order to motivate and facilitate English as second language (ESL) learning of first year of Bachillerato (year 12) students at a public high school in the Region of Murcia (Spain) and following an action research methodology, we design, implement and evaluate a role-playing game, which consists of the creation and management of a company, The Tik Tok School. The results confirm that students felt more comfortable speaking in English because they were more motivated. They also state that during the experience they were more focused on learning rather than winning the game and that they prefer a gamification approach over traditional settings. Furthermore, they have been participating constantly using more English than Spanish. After the data analysis, we conclude that this methodology positively impacts motivation and the acquisition of a second language.

Keywords: role-playing games; gamification; second language instruction

Citation: Hernández-Prados, M.Á.; Belmonte, M.L.; Manzanares-Ruiz, J.C. How to Run Your Own Online Business: A Gamification Experience in ESL. *Educ. Sci.* **2021**, *11*, 697. https://doi.org/10.3390/educsci11110697

Academic Editors: José Carlos Piñero Charlo, María Teresa Costado Dios, Enrique Carmona Medeiro and Fernando Lloret

Received: 20 August 2021
Accepted: 28 October 2021
Published: 31 October 2021

1. Introduction

Education is important for the development of societies. Therefore, there is a constant search to improve it, in which innovative education plays a crucial role [1], as it involves the implementation of other ways of completing the educational task that contribute to enhancing the behaviors of individuals, organizations and economies. Nowadays, most teachers have opted for innovative education to transform and upgrade educational practice, although there are still many that feel more comfortable with traditional teacher-centered methods. Gamification is one of the most significant methodologies within innovative education [2–7], maybe due to the many advantages that it is said to have. It is a groundbreaking methodology that is here to stay, as many others have in the past.

To avoid the usual confusion regarding gamification and some associated terms, some definitions are commonly used. Deterding et al. [8] (p. 1) understood gamification as "the use of game design elements in non-game contexts", in this case, the educational field in order to motivate and engage people [6]. It is a process that contributes to "making activities more game-like" [9] (p. 266), applying the characteristics and benefits of games to real-world processes and problems [7]. Gamification is based on game mechanics, aesthetics and reasoning to motivate and promote learning [10], and the main difference between ludification and gamification is that the former prioritizes the recreational aspect [11], whereas the latter matches the educational curriculum with skills students will need in their lives [12], focusing on competences. For the purposes of this study, gamification is understood as an unbeatable opportunity to generate active learning environments in which students learn curricular content in a relaxed, collaborative, dynamic and experiential environment.

Within the most common elements that make a gamified experience, some stand out: avatars, badges, boards, prizes and stories [5,13]. Visual support can also be used, especially at the beginning of the gamification, to engage the students [14]. Considering the literature review conducted by Dehghanzadeh et al. [15], the most used elements are feedback, challenges, points and rewards. The latter is achieved by winning experience points when you master some activity or achieve a milestone [16]. Furthermore, gamified curricular design involves three main elements: abstraction (transform real-world scenarios into a series of challenges), mechanics, and interfaces, which are designed to invite continuous participation [16].

The growing research on gamification has led to the proliferation of gamified educational experiences. Unfortunately, only a few have been evaluated. In fact, there is very little literature on the development and assessment of innovative educational programs [8], so that the debate on the effectiveness and improvements attributed to gamification continue to be open. The relevance of this research is the evaluations that students make of a role-playing gamification experience. The following questions can be answered: To what extent does this innovation promote the motivation and attention of students? Does it really improve learning and academic performance? To what extent does it affect the acquisition and implementation of competencies? Additionally, more specifically in relation to ESL, how does gamification contribute to the improvement of linguistic competence? In this study, students had to create a company from scratch, deciding, in the so-called team meetings, how they are going to run the business, pay their taxes and the best way to advertise themselves. The main objective of the role-playing is learning to become successful Tiktokers, which is why it is named the Tik Tok School. Through this experience, we intend to work on the acquisition of skills focused on economic management, entrepreneurship, communication processes, negotiation and decision making, among others.

There are different types of gamification in the educational field [17]. Regarding the contents, there are two subtypes: the structural one, in which the contents do not vary, but some gamified elements are added, and the content one, in which gamification is applied to both the contents and the structure, to have a game-like appearance, but we can also classify gamification according to whether it is a punctual action or the complete syllabus of a course [2]. From this point of view, the experience carried out is a punctual action in the syllabus of the English course that fits the second of the described modalities.

Precisely, making a new learning environment is one of the multiple challenges that teachers face. Furthermore, once the multiple benefits attributed to gamification are recognized, the question to be asked is: could these benefits be applied in ESL? More specifically, the following research problem was posed: what effects, achievements and difficulties arise from the application of role-playing games in ESL? As we detail throughout this paper, innovative methodologies in education, and more specifically gamification, are increasingly relevant as a method to help secondary school students improve their English skills [3], such as in a role-playing experience using puppets, with results showing that students improved their oral skills such as pronunciation and fluency [18]. Considering this context, this study has a twofold objective. On the one hand, it aims to provide a gamified intervention program, which increases the motivation with which students perceive the ESL class. On the other hand, it analyzes the students' perceptions, within the context of ESL and after carrying out such an intervention, about their proficiency levels, role-playing games, educational gamification and English use during the game.

Specifically, we started from a state of the art of gamification as a methodological resource in the ESL classroom, then moved on to the design, implementation and evaluation of an educational experience based on a role-playing game in which a group of first-year Bachillerato students (Year 12) had to create their own company, facing some difficulties during the process.

2. Theoretical Framework

2.1. Literature Review: Gamificación in English as Second Language

Since Wittgenstein adapted many board games for teaching English, particularly card games, and coined the concept of language games [19], the literature about this topic has evolved considerably; in fact, there are several gamification experiences related to language learning. More specifically, Dehganzadeh and Dehganzadeh [20] identify English as the language in which gamification is most used, mainly to teach vocabulary and, to a lesser extent, grammar.

If we want gamification to be increasingly used when teaching English, we must understand how it is currently being used and design strategies to help teachers implement it. In the study conducted by Singh et al. [21], several ESL experiences are analyzed, and they conclude that new technologies provide teachers with sufficient resources to gamify curricular content. Likewise, students showed more willingness to use mobile applications to learn languages in the future and positively valued the interaction possibilities [22].

Within gamification studies, the use of online quiz-type tools such as Quizzizz or Kahoot! stands out. The main positive aspects highlighted by Jiménez-Sánchez and Gargallo [23] are that they make classes more fun and have a competitive factor. However, role-playing games do not usually use external applications but rely on the creation of a gamified game environment.

In another ESL experience focused on traditional African stories called Ubuntu, students were introduced to different social contexts, approaching other cultures and creating their narratives while expanding their lexical knowledge and understanding better the components of a story. Furthermore, it fostered creativity and critical thinking [24]. Similarly, Lam et al. [25] developed critical thinking and argumentative writing in high-school students through gamification. They conclude that is a more effective method than teacher-led direct instruction as it promotes writing longer, more creative and critical texts with the appropriate argumentative and structural components. Moreover, the subsequent on-line discussion allows students to read and reply to their peers' contributions, favoring interaction and feedback.

On the one hand, other investigations analyze the effect of role-playing games on learning English vocabulary, such as the one led by Fahim and Sabah [26]. They had similar results as before: students valued gamification positively and performed better than the control group. Another experience conducted by Girardelli [3] proved that when using gamification and role-playing games, trying to imitate a famous American TV show, students gained confidence when making short interventions in English and were more aware of the importance of organizing their speech and of non-verbal communication. On the other hand, Yen et al. [27] designed a mobile application focused on learning English vocabulary. It showed that students increased the time they spent using English and their proficiency level compared to the control group.

2.2. The Use of Role-Playing Games in Education

Of the different gamification approaches, this paper focuses on role-playing games. In 1974, *Dungeons and Dragons* was published, considered the world's first role-playing game, and it defined many of the characteristics and canons still in use. It established that imagination should be used and emphasized the need to perform a role [28]. A role-playing game could be defined as a shared fiction that develops some type of narrative with no predefined script in which each player assumes a specific role and acts consequently [29,30]. This is the main difference with another gamification modality: simulation. For this reason, due to the choices made by the players there will be no two similar role-playing games, even if they are based on the same story. Furthermore, during the game, the characters will develop and obtain new skills [31]. Finally, Mackay [32] adds the idea that a role-playing game must be "episodic", that is, it has to be carried out in several sessions, not just in one.

A role-playing game is a tool that will allow teachers to introduce real life-like activities with which students can understand more deeply a topic. For example, in the study of Gordon [33], students learnt the differences between American and Mexican cultures. Additionally, they acquired new vocabulary such as "pyramid, Aztecs or archaeological dig" (p. 713). Nuriyanti [34] states that to know a language means being able to use it in written and oral form to express your feelings or ideas, regardless of the context. This type of gamified methodologies, such as role-playing games, aim to increase students' level of confidence speaking English so that their oral expression can make quantitative and qualitative improvements. Research conducted by Ayuningtias et al. [35], which compares teaching the same content in two ways, traditional memoristic learning and role-playing, showed that students participated more actively in their own learning in the latter. This ended up increasing their enthusiasm, motivation and, therefore, their oral expression skills. As these kinds of games are based on storytelling, they can help pass oral traditions and narratives through mix with popular culture to younger generations.

Like any methodology, gamification has supporters and a detractor who discuss its educational use in an open debate. The former argue that it is an active, student-centered methodology that faces learning with a different attitude and motivation that compensated for the generalized students' disinterest in the curriculum [11]. It is ideal for creating learning environments that actively involve, engage and motivate people and favor conflict resolution in the learning process [10]. It makes ESL classes more fun and, therefore, more motivating for students. The more motivated the students are, the more "effective" the activities carried out [36]. Among role playing games' most motivating characteristics, those that stand out are leaderboards, experience points and badges [4]. Moreover, this methodology promotes students' autonomy and improves leaning outcomes similarly to how the brain learns than traditional teaching [37].

Using role-playing games, students can contribute to blended assessments, seeking new solutions to the posed problems, justifying their opinions and assessing their peers [38]. Likewise, through gamification teachers can assess content in an integrative way [11], so that students feel that their efforts will be rewarded with different instruments not only with a single final evaluation. In another study carried out by Purnama and Nurdianingsih [39], the conclusion is that if we want to improve the oral expression of our students, teachers need to focus on higher order thinking skills and one way to do so is by through role-playing games

Nevertheless, not everything surrounding gamification and role-playing games is positive. There are also some negative aspects. One of the most mentioned is the difficulty and effort involved in its design, as the teacher must prepare everything thoroughly so that the teaching–learning process achieves the proposed objectives [34]. Jassen [40] supports this idea by arguing that it is a demanding methodology; therefore, the teacher will need to prepare for each experience. In addition to a clear objective that provides content and meaning to the experience, specific training and a certain technological mastery are required to prepare, design and develop each session. These reasons may be the reason that its use is still not very widespread, despite all the potential benefits [12].

As we have presented, there have been several gamification studies in ESL classrooms, with each one using a different technique: mobile applications, video games, role-playing games, etc. Nevertheless, all of them have something in common, the positive assessment and more significant progress of the participants. In the studies presented, motivation, satisfaction, and grades in English increased more in the gamified learning group than in the control group. In fact, in a literature review by Dehghanzadeh et al. [15], the most repeated words about the gamification experience were enjoyable, interactive and exciting, not finding any negative evaluation. Moreover, a role-playing game experience using students studying for an engineering degree showed that the game itself was the most useful learning element during the course [41]. However, other variables such as classroom activities and demographics have not been considered to elaborate on such studies, so the conclusions are still at a preliminary stage [42]. As Ishaq et al. [43] found, mobile learning allows students to learn remotely and adapt their routines to their circumstances. Another app to consider is "Grammar Grabber", which makes it possible to evaluate the student's grammatical knowledge while receiving constant feedback. Moreover, it is possible to repeat incorrect answers [44].

Thanks to role-playing games, students can work on not only the main content but also on some transversal elements—for example, using French as a means of learning about the Enlightenment and the history of France [45].

3. Materials and Methods

This experimental study is based on an objectivist model, following a quantitative paradigm [46].

3.1. Participants and Context

The gamified experience was carried out in a public secondary school of Murcia (Spain), during the academic year 2020–2021.

The participants are part of a bilingual English–Spanish group in their 1st year of Bachillerato (year 12). As can be observed in Table 1, it is made up of 12 students (7 girls and 5 boys). None of them needed educational support. A large majority were 16 years old at the time of the research. It is noteworthy that none of them had lived in an English-speaking country and just a few have English-speaking relatives. In addition, most of them do not attend private English classes.

Table 1. Sample distribution of participating students.

Variables	Options	Percentage	Frequency
Age	16	75%	9
	17	25%	3
Gender	Girl	58.3%	5
	Boy	41.7%	7
Attend private classes	Yes	41.7%	5
	No	58.3%	7
English-speaking relatives	Yes	25%	3
	No	75%	9
Lived in an English-speaking country	Yes	0%	0
	No	100%	12

The most significant aspect is undoubtedly the little contact that the students have with English outside the classroom. As we can see, none of them have lived in an English-speaking country and a large majority (75%) do not have English-speaking relatives. This is reinforced by the fact that only 41.7% of the students attend English private classes.

3.2. Methods

There are three stages in this investigation. The first one was a literature review about educational gamification. Subsequently, we designed and prepared all the materials used, following the previously studied guidelines. The second phase consisted of the implementation of the role-playing game and the gamified sessions with the students. Once the students had completed the experience, they assessed the experience through a questionnaire. Finally, we analyzed the data collected, considering the following parameters: gender, attendance to English private classes and having English-speaking relatives.

Implementing a gamified didactic unit implies reorganizing the teacher–student relationship, as the game has been designed for peer groups. In this sense, and considering the role-playing game format, formality and professionalism must be two of the main features that mark students' relationships among themselves and with the teacher, since they must remain as true as possible to their assigned characters. Therefore, the terminology and forms of politeness must be appropriate for the situation [47].

The role-playing game is designed to work on the vocabulary, grammar and expressions students have learned during theoretical sessions. It consisted of creating a company, the Tik Tok School, in which the students had to face the challenges of any entrepreneur. Such challenges were to find the first students, how to deal with a tax payment or, once the students arrived, how to run the school successfully.

Before a role-playing game starts, players must complete a character sheet with basic features and valuable information. This sheet must be updated as the game progresses [48]. In our study, we designed three character sheets (Figure 1), depending on the role each student chose. The first one is the CEO, who oversees decisions made at the company as well as makes sure it is profitable; the marketing person, who is in charge of advertising the company on social media; and the teacher, who is responsible for designing the classes. The organizational chart that the students made is in Figure 2. To help them internalize their characters and play their roles as partners in a company, they had to fill in some details such as weaknesses, strengths or objectives. Depending on the moment, the teacher may act as a representative of tax authorities or a television reporter, among others.

Figure 1. Example of one of the character sheets used in the role-playing game.

Figure 2. Organizational chart of the company.

On the one hand, a game handbook was designed with the company logo (Figure 3) and the objectives to be achieved in each team meeting, with space to take notes and plan the strategies to be followed. We also used task cards that some students received during the experience, such as the letter from Her Majesty's Revenue and Customs (HMRC) (Figure 4), demanding a fine for non-payment.

Tik Tok School

WHERE DREAMS COME ON VIDEO

Figure 3. Company logo.

HM Revenue & Customs

Tik Tok School
King Peter Street, 8
Oxford

HM Revenue and Customs
BX9 1AS
London
0300 123 1813
www.hmrc.gov.uk

Date of issue: 2nd April 2021
Reference: 120 P M 5632 753

New debt - amount due £ 2000.00

Dear Sir or Madam,

Our records show that we agreed to a payment plan to help you bring your tax affairs back on track, but that you now have a new debt. You accepted these conditions. That is why you must pay this new debt immediately and ensure that all future tax payments are made on time.

You can pay by debit or credit card by calling us on the number above. To pay online, and for more information about payment, please go to www.hmrc.gov.uk/payinghmrc

Yours faithfully,

Office of Revenue and Customs

HM Revenue & Customs
HM Revenue and Customs, X9 1AS, London

Figure 4. HMRC Letter.

These cards have the function of giving more dynamism to the game, since some characters during the team meetings will have to carry out the secret mission that appears in each one.

On the other hand, gamified activities were integrated within the role-playing game itself. For example, to practice vocabulary related to economy and money, we designed an activity inspired by the board game Taboo. Moreover, we used an activity based on the Battleship game to practice the passive voice. Finally, we used classroom discussions to learn some structures to show agreement/disagreement, ask for someone's opinion, etc.

Likewise, we used two videos (Figure 5) so that students could get into the character more effectively during the game. The first one was used to introduce the experience and to help students choose their characters. We played the second video at the end of the experience. It was a news program showing that the students had won an innovation award. Finally, they had an informative note about the game posted on Google Classroom. It was a summary of how the experience worked.

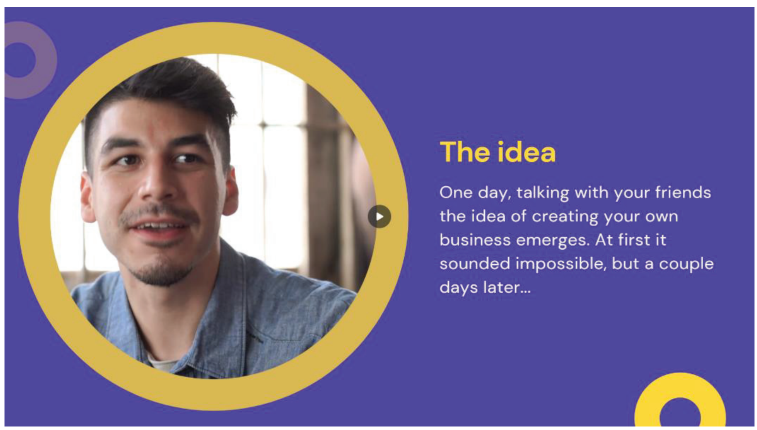


Figure 5. Extract from the introduction video.

Among the ethical considerations that were considered, it should be noted that all participants received relevant information about the project in two different ways: information sheets and an oral presentation in the classroom. As it is an innovative methodology, they were informed that they all had to participate in the learning experience to acquire the didactic unit's curricular competencies. However, they could refuse to participate in the completion of the questionnaire that evaluated it. As the participants were minors, the families received an informed consent form emphasizing that participation in the data collection through the questionnaire was voluntary, and that all data collected were anonymous and kept in a safe place. The choice to participate was not conditioned or pressured, since the research team is external to the educational center, and it was made clear to the students that failure to complete the questionnaire would not affect the grade for the subject, since the subject coordinator would not have this information.

3.3. Data Collection Instrument

The questionnaire used [49], which has been previously validated, has the ultimate goal of determining and analyzing the perception that secondary school students have of ESL learning through games and gamification. The instrument is divided into several sections. The first one integrates sociodemographic questions and questions aimed at finding out the students' proficiency levels and relationships with English. The following 28 items are closed-ended, with a five-grade Likert-type scale (1: strongly disagree; 2: disagree; 3: neither agree nor disagree; 4: agree and 5: strongly agree). These are further subdivided into four dimensions. The first seven items are dedicated to role-playing games, the next six to the gamification sessions, the following six to the use of the English language in the game and the last nine to find out their general opinion.

3.4. Data Collection Techniques

The technique used to analyze the information obtained is statistics and, specifically, descriptive analysis. It is used to summarize the information contained. Version 24.0 of the Statistical Package for the Social Sciences (SPSS) predictive and graphic analytics platform was used for analyzing the data.

4. Results

This section may be divided into subheadings. It should provide a concise and precise description of the experimental results, their interpretation, and the experimental conclusions that can be drawn.

4.1. Students' Perceptions about Their Own Proficiency Level, Once the Gamification Is Over

The descriptive statistics of the research variables, specifically the mean scores ($\tilde{X}$) and standard deviations (σ), of the purpose stated in the study, are shown below.

As Table 2 shows, students' have intermediate proficiency levels ($\tilde{X}_{PA1.3}$ = 3.58). More specifically, they state they have better oral ($\tilde{X}_{PA1.4}$ = 3.92) and written ($\tilde{X}_{PA1.5}$ = 3.92) comprehension. However, their production proficiency levels, both oral ($\tilde{X}_{PA1.6}$ = 3.58) and written ($\tilde{X}_{PA1.7}$ = 3.50), are average.

Table 2. Descriptive statistics of students' perceptions of their English proficiency levels.

	$\tilde{X}$	σ
A1.3. My overall proficiency level is:	3.58	0.669
A1.4. My oral comprehension proficiency level (listening) is:	3.92	0.793
A1.5. My written comprehension proficiency level (reading) is:	3.92	0.996
A1.6. My oral production proficiency level (speaking) is:	3.58	0.793
A1.7. My written production proficiency level (writing) is:	3.50	0.798

4.2. Student's Perceptions about the Use of Role-Playing Games in the ESL Classroom Once the Gamification Is Over

Regarding students' opinions about the use of role-playing games in the English classroom, Table 3 shows that they believe that role-playing games help them improve their speaking ($\tilde{X}_{PB1.2}$ = 4.50) and listening ($\tilde{X}_{PB1.1}$ = 4.33) skills. Moreover, they state that they feel more comfortable and confident to speak English in the classroom ($\tilde{X}_{PB1.5}$ = 4.33) and, above all, board games motivate them to participate more ($\tilde{X}_{PB1.6}$ = 4.42), fostering peer interrelations ($\tilde{X}_{PB1.7}$ = 4.08).

Table 3. Descriptive statistics of students' perceptions about the use of board games in the ESL classroom.

	$\tilde{X}$	σ
B1.1. They help improve my oral comprehension skills (listening).	4.33	0.778
B1.2. They help improve my oral production skills (speaking).	4.50	0.798
B1.3. They help improve my written comprehension skills (reading).	3.75	1.215
B1.4. They help improve my written production skills (writing).	3.50	1.168
B1.5. They help me to be more confident when speaking in English	4.33	0.778
B1.6. They motivate me to participate in class.	4.42	0.669
B1.7. They help meet and get to know better with my classmates	4.08	1.084

4.3. Students' Perceptions about Educational Gamification in the ESL Classroom Once the Gamification Is Over

As Table 4 shows, students believed that they all had the opportunity to participate in the game ($\tilde{X}_{PB.2.6} = 4.75$) and that they have focused more on learning and enjoying rather than on winning ($\tilde{X}_{PB.2.3} = 4.75$). Moreover, they participated constantly during the game ($\tilde{X}_{PB.2.2} = 4.67$) and spoke more in English than in Spanish ($\tilde{X}_{PB.2.1} = 4.53$).

Table 4. Descriptive statistics of students' perceptions about the educational gamification in ESL.

	$\tilde{X}$	σ
B2.1. I have spoken more in English than in Spanish	4.53	0.559
B2.2. I have been participating constantly during the game	4.67	0.778
B2.3. I have been more focused on learning and enjoying rather than winning	4.75	0.622
B2.4. I have respected my classmates' turn to play.	4.42	0.793
B2.5. I have listened to my classmates and respected their speaking time	4.25	0.866
B2.6. Everyone could participate more than once during the game	4.75	0.622

4.4. Students' Perceptions about the Use of English during the Game Once the Gamification Is Over

As reflected in Table 5, students claim to have been able to understand their peers' points of view ($\tilde{X}_{PB.3.2} = 4.42$), having always or almost always used English to communicate ($\tilde{X}_{PB.3.3} = 4.42$). In addition, they stated they have always or almost always answered in English to the teacher ($\tilde{X}_{PB.3.6} = 4.25$), understanding all or almost all conversations held in English with peers and/or the teacher ($\tilde{X}_{PB.3.1} = 4.25$).

Table 5. Descriptive statistics of students' perceptions about the use of English during the gamification.

	$\tilde{X}$	σ
B3.1. I have understood all or almost all conversations held in English with my classmates and/or the teacher.	4.25	0.588
B3.2. I have been able to understand my classmates' points of view.	4.42	0.793
B3.3. I have spoken in English always or almost always to speak with my classmates.	4.42	0.900
B3.4. I have spoken in English always or almost always with the teacher.	4.08	0.669
B3.5. I have been able to answer always or almost always in English to my classmates when they have posed a question.	4.08	0.793
B3.6. I have been able to answer always or almost always in English with the teacher when he has posed a question.	4.25	0.754

4.5. Students' General Perceptions about the Gamified Experience

Finally, as Table 6 shows, students assess gamification sessions as a very effective tool to improve their English proficiency level ($\tilde{X}_{PB.4.2}$ = 4.75). Moreover, they generally prefer them to other types of activities ($\tilde{X}_{PB.4.3}$ = 4.58), because they are, according to them, more entertaining than a traditional session ($\tilde{X}_{PB.4.1}$ = 4.58). In addition, they find it a very good idea to learn English while playing ($\tilde{X}_{PB.4.4}$ = 4.67).

Table 6. Descriptive statistical of students' perceptions about their general opinion about the experience.

	$\tilde{X}$	σ
B4.1. I like the gamification sessions because they are entertaining and motivate me to continue learning.	4.58	0.669
B4.2. I believe that the gamification sessions are effective to improve my English proficiency level.	4.75	0.622
B4.3. I prefer these activities than the usual ones that I do in ESL classes.	4.58	0.669
B4.4. I think it is a good idea to learn English while I play.	4.67	0.651
B4.5. Instructions have been clear and easy to understand.	4.42	0.793
B4.6. There has been enough playing time.	4.42	0.900
B4.7. The classes were well organized.	4.67	0.651
B4.8. The game materials are related to the topics learned in the didactic unit.	4.58	0.793
B4.9. I found it easy to follow the activities.	4.42	0.79

5. Discussion

Throughout the study, we have been detailing the benefits that role-playing games and educational gamification in general regarding motivation and improving students' outcomes [6,23,36,39]. Therefore, the relevance and appropriateness of the design, implementation and evaluation of gamified didactic units in the classroom are amply justified. Furthermore, the results obtained show that students prefer gamified sessions to traditional teaching methods. This verifies what has been previously stated by authors such as Sarmiento et al. [11], Kapp [10], Hernández-Ramos and Belmonte [36] or Rueckert et al. [37].

The role-playing game described in this paper was based on creating a company, improving the disciplinary curricular content and the students' entrepreneurship skills, teamwork and motivation. Although there is no perfect methodology to work on entrepreneurship, the results can be improved as it is an experiential learning tool [50]. Moreover, gamification can achieve the paradigm shift from teacher-centeredness to student-centered teaching [11].

Regarding their English proficiency levels, students started from an average perception in all skills: listening, reading, speaking and writing, with the last two being the lowest ones, and therefore the ones that need to be improved. Even though speaking is always the most difficult skill that students find, they do not practice enough due to practical difficulties, such as anxiety, embarrassment or mistake phobia [51]. The results obtained after the evaluation of the experience by the students indicate that the skill they claim they most improved is speaking. As we have previously indicated, gamification had very positive results for teaching verb tenses [5], vocabulary [52] and for fostering more interaction among students [22]. In fact, some studies claim that through role-playing games students improve this skill as they express themselves actively and meaningfully, while fostering their creativity [53].

On the other hand, the scientific discourse on gamification in terms of the gender variable has a long history in which the initial supremacy of men in the video game industry led not only to the proliferation of men playing them, but also to an exaltation of sexualized women. However, the review by Lynch et al. [54] notes a greater presence of women as protagonists in games and a clear preference for role-playing games over other types of games and less sexualized features. In terms of teamwork, it should be noted that during the gamified intervention using role-playing games, students consider that everyone has had the opportunity to participate in the game, having focused more on learning and enjoying themselves than on winning. Role-playing games are a tool with which students must work in teams to achieve the same objectives, as they would do in the real world [55]. In addition, they claim to have maintained a constant level of participation throughout the game, having spoken more in English than in Spanish.

It is also worth mentioning the positive evaluations they make about how motivating the experience is, being a direct consequence of this, they feel more comfortable speaking English in the classroom, corroborating the studies of Sarmiento et al. [11] and Kapp [10].

Finally, we would like to mention the future possibilities and limitations of this study. Undoubtedly, the most important one is the limited number of participants with whom we could work. It would be advisable to repeat the experience with more students and a control group. Moreover, if it could be repeated in another educative context, i.e., with a non-bilingual class, more complete conclusions could be drawn.

In other previous studies in which gamification and role-playing games have been used to teach curricular content, other sociodemographic variables have not been considered [42]. Therefore, although all the results corroborate the relevance of this methodology, it is necessary to know the context in which we are working to maximize the results.

One of the difficulties related to the teaching–learning process, and not so much to the game itself, stems from having to work collaboratively in hybrid educational contexts derived from the COVID situation [56], and with the need to maintain social distance. Due to the use of masks, it was really complicated to understand the pronunciation, the gesticulation and dramatization accompanying the role-playing games, the preparation and work of the group outside the school premises, the exchange of materials, etc.

On the other hand, some difficulties derived from the designed game were detected regarding the excessively specialized and technical vocabulary used in some elements of it, such as the HMRC letter. The lack of experience of the students in these dynamics was reflected in the insecurity of not controlling the game and how the decisions taken in each of the challenges affected them, as well as in the lack of criteria, knowledge and arguments for making business decisions, making it difficult to stimulate the debates in the work groups. Moreover, the lack of familiarity with the role-playing strategy, shyness and fear of communicating in the classroom, together with the work overload for teachers and students, are two of the limitations associated with the game itself [57].

Regarding the teacher–student relationship, the role as facilitator played by the former should be emphasized. Sometimes students get carried away by fun and entertainment, overshadowing learning; therefore, it is important that the teacher acts as a moderator, taking control of all roles, redirecting the process and fostering students' motivation and their intention to act [58,59]. They were to act as different characters depending on the situation, whether as a television reporter or someone looking for information about the school. Moreover, it has been demonstrated that the teacher also enjoyed these kinds of games and is looking forward to seeing how the game develops [18]. There were some moments when the students were stuck, so he would intervene by mentioning some guidelines for them to follow. Furthermore, in the team meetings, the teacher would ask questions to stimulate the discussions and to encourage new ideas. He needs to be supportive through feedback, to help students overcome the fear of speaking in public and to create a climate of trust and respect. Thanks to this, students become more spontaneous and enthusiastic [57].

As this was a gamification experience in ESL, the teacher also had to resolve the linguistic doubts that arose, both so that the students could express themselves and so that they could understand the situations that were being presented. Finally, the role of the teacher was basically that of a game master, i.e., the person in charge of the game, of setting the timing, of establishing and finalizing new challenges, among others.

Some of the challenges that the students faced as entrepreneurs were, first, to find an innovative idea. Role-playing games can raise awareness of entrepreneurial spirit [60], which is a powerful economic tool for the future of a country [61]. However, as this was partially delimited in the introduction of the role-playing game, the students had to show their creativity in delimiting the aspects of content, marketing, target audience, structure, organization chart of the company, etc. Afterwards, they had to look for a way to finance their project and, once this was obtained, to pay their taxes. When the company was operational, one of the main difficulties encountered by any entrepreneur or worker is managing business conflicts and interpersonal relations between workers and employers. Persuasive communication, which is vital in the business world and not so often taught in schools [60], is a key element of these relationships and one way to work on this is through role-playing games as they foster students' confidence when speaking. Regarding conflicts, role-playing games positively influence students' self-efficacy in problem solving, critical thinking and teamwork [62]. This is supported by another study which concludes that entrepreneurship education through role-playing games is a completely effective and valid method [61]. As Radianto and Santoso [63] state, the entrepreneurship process has two main aspects: the financial and non-financial ones. It is crucial that the teacher understands how students are running their business to give them proper guidance.

In conclusion, we would like to highlight the importance that gamification and other innovative methodologies have and will have in education due to their educational implications and the good results they have been obtaining. Similarly, we would like to emphasize the need for teachers to be trained in gamification, which, as indicated by Jassen [40], is a very demanding methodology for them. However, as have been detailed in gamification studies, they achieve excellent results [15,35,52]. In addition, we believe that more training in new technologies and innovative methodologies will reduce the time needed to create new gamified experiences and the insecurity of some teachers when employing them in the classroom [64].

Author Contributions: Conceptualization, M.Á.H.-P. and J.C.M.-R.; methodology, M.L.B.; validation, M.Á.H.-P. and M.L.B.; formal analysis, J.C.M.-R.; investigation, J.C.M.-R.; resources, J.C.M.-R.; data curation, M.L.B.; writing—original draft preparation, J.C.M.-R.; writing—review and editing, M.Á.H.-P.

and M.L.B.; visualization, M.Á.H.-P.; supervision, M.Á.H.-P. and M.L.B.; project administration, M.Á.H.-P. 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 the protocol was approved by the schools where the study took place.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study. Moreover, the school involved authorized this research project.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy.

Acknowledgments: We would like to thank the teachers, students and families of the high school where the project was developed for the possibility of developing it.

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

References

1. Aithal, P.S.; Aithal, S. An innovative education model to realize ideal education system. *Int. J. Sci. Res. Manag. (IJSRM)* **2015**, *3*, 2464–2469.
2. Garone, P.; Nesteriuk, S. Gamification and Learning: A Comparative Study of Design Frameworks. In *Digital Human Modeling and Applications in Health, Safety, Ergonomics and Risk Management*; Duffy, V., Ed.; Healthcare Applications, HCII 2019; Lecture Notes in Computer Science; Springer: Cham, Switzerland, 2019; Volume 11582, pp. 473–487.
3. Girardelli, D. Impromptu speech gamification for ESL/EFL students. *Commun. Teach.* **2017**, *31*, 156–161. [CrossRef]
4. Hamari, J.; Koivisto, J.; Sarsa, H. Does Gamification Work?—A Literature Review of Empirical Studies on Gamification. In Proceedings of the Hawaii International Conference on System Sciences, Waikoloa, HI, USA, 6–9 January 2014; pp. 3025–3034. [CrossRef]
5. Sourav, A.I.; Lynn, N.D.; Suyoto, S. Teaching English tenses in an informal cooperative study group using smart multimedia and gamification. *IOP Conf. Ser. Mater. Sci. Eng.* **2021**, *1098*, 032035. [CrossRef]
6. Su, C.-H.; Cheng, C.-H. A mobile gamification learning system for improving the learning motivation and achievements. *J. Comput. Assist. Learn.* **2014**, *31*, 268–286. [CrossRef]
7. Wortley, D. The Future of Serious Games and Immersive Technologies and Their Impact on Society. In *Trends and Applications of Serious Gaming and Social Media*; Springer: Singapore, 2014; pp. 1–14. [CrossRef]
8. Deterding, S.; Dixon, D.; Khaled, R.; Nacke, L. From game design elements to gamefulness: Defining gamification. In Proceedings of the 15th International Academic MindTrek Conference: Envisioning Future Media Environments, Tampere, Finland, 28–30 September 2011; ACM: New York, NY, USA, 2011.
9. Werbach, K. (Re)Defining Gamification: A Process Approach, persuasive technology. *Lect. Notes Comput. Sci.* **2014**, 266–272. [CrossRef]
10. Kapp, K. *The Gamification of Learning and Instruction: Game–Based Methods and Strategies for Training and Education*; John Wiley & Sons: Hoboken, NJ, USA, 2012.
11. Sarmiento, B.R.; Prados, M.H.; Bernal, N.C.; Gómez, M.C.A. Alfabetización del profesorado en gamificación mediada por las TIC. Estado del arte. *Med. Educ.* **2021**, *12*, 53–65. [CrossRef]
12. Peris, F.J.S.I. Gamificación. *Educ. Knowl. Soc. (EKS)* **2015**, *16*, 13–15. [CrossRef]
13. Parreño, J.M.; Ibáñez, E.M.; Arroyo, A.A. The use of gamification in education: A bibliometric and text mining analysis. *J. Comput. Assist. Learn.* **2016**, *32*, 663–676. [CrossRef]
14. Villagrasa, S.; Fonseca, D.; Redondo, E.; Duran, J. Teaching Case of Gamification and Visual Technologies for Education. *J. Cases Inf. Technol.* **2014**, *16*, 38–57. [CrossRef]
15. Dehghanzadeh, H.; Fardanesh, H.; Hatami, J.; Talaee, E.; Noroozi, O. Using gamification to support learning English as a second language: A systematic review. *Comput. Assist. Lang. Learn.* **2019**, 1–24. [CrossRef]
16. Yunyongying, P. Gamification: Implications for Curricular Design. *J. Grad. Med. Educ.* **2014**, *6*, 410–412. [CrossRef] [PubMed]
17. Kapp, K.; Blair, L.; Mesch, R. The gamification of learning and instruction fieldbook. In *Ideas into Practice*; Wiley: Hoboken, NJ, USA, 2013.
18. Kurniatun, F.; Suhartono, L.; Wardah, W. Improving students' speaking skill through role play activity by using hand puppet. *J. Pendidik. Dan Pembelajaran Khatulistiwa* **2020**, *9*, 1–9.
19. Das, D.; Neog, R. Language game: Ludwig wittgenstein. *Int. J. Manag.* **2020**, *11*, 143–148. [CrossRef]
20. Dehganzadeh, H.; Dehganzadeh, H. Investigating effects of digital gamification-based language learning: A systematic review. *J. Engl. Lang. Teach. Learn.* **2020**, *12*, 53–93.
21. Singh, C.; Ong, E.; Singh, T. A review of research on teachers' views on integrating gamification and technology in english as second language classroom. *J. Crit. Rev.* **2020**, *7*, 4333–4341. [CrossRef]

22. Abarghoui, M.A.; Taki, S. Measuring the Effectiveness of Using "Memrise" on High School Students' Perceptions of Learning EFL. *Theory Pract. Lang. Stud.* **2018**, *8*, 1758–1765. [CrossRef]
23. Jiménez-Sánchez, M.; Gargallo, N. Gamification and Students' Motivation: Using Quizizz in the English as a Foreign Language (efl) Classroom. *Studia Universitatis Petru Maior. Philologia* **2020**, *2*, 143–157. Available online: https://www.proquest.com/scholarly-journals/gamification-students-motivation-using-quizizz/docview/2475532461/se-2?accountid=17225 (accessed on 23 March 2021).
24. Oliveira, S.; Porto, I.P.D.; Cruz, M. The Gamification Octalysis Framework within the Primary English Teaching Process: The Quest for a Transformative Classroom. *Rev. Lusófona Educ.* **2018**, *41*, 63–82. [CrossRef]
25. Lam, Y.W.; Hew, K.F.; Chiu, K.F. Improving argumentative writing: Effects of a blended learning approach and gamification. *Lang. Learn. Technol.* **2017**, *22*, 97–118.
26. Fahim, M.; Sabah, S. An Ecological Analysis of the Role of Role-play Games as Affordances in Iranian EFL Pre-university Students' Vocabulary Learning. *Theory Pract. Lang. Stud.* **2012**, *2*, 1276. [CrossRef]
27. Yen, L.; Chen, C.; Juang, H. Effects of Mobile Game-Based English Vocabulary Learning APP on Learners' Perceptions and Learning Performance: A Case Study of Taiwanese EFL Learners. Academic Conferences International Limited: Sonning Common, UK, 2016.
28. Mentzer, F. *Dungeons & Dragons: Players Manual*; TSR Hobbies Inc.: Lake Geneva, WI, USA, 1983.
29. Moreno-Guerrero, A.-J.; Rodríguez-Jiménez, C.; Gómez-García, G.; Navas-Parejo, M.R. Educational Innovation in Higher Education: Use of Role Playing and Educational Video in Future Teachers' Training. *Sustainability* **2020**, *12*, 2558. [CrossRef]
30. Nellhaus, T. Online Role-playing Games and the Definition of Theatre. *New Theatr. Q.* **2017**, *33*, 345–359. [CrossRef]
31. Ntokos, K. Swords and sorcery: A structural gamification framework for higher education using role-playing game elements: Association for Learning Technology Journal. *Res. Learn. Technol.* **2019**, *27*. [CrossRef]
32. Mackay, D. *The Fantasy Role-Playing Game: A New Performing Art*; McFarland & Company: Jefferson, MO, USA, 2001.
33. Gordon, T. Using Role-Play to Foster Transformational and Social Action Multiculturalism in the ESL Classroom. *TESOL J.* **2012**, *3*, 698–721. [CrossRef]
34. Nuriyanti, K. *Using Role-Play Techniques to Improve Speaking Ability for Students in the Classroom*; Universidad Islámica de Malang: Medina, Saudi Arabia, 2017.
35. Wulandari, W.; Ayuningtias, D.O.; Yana, Y. The use of role play to improve students' speaking skill. *Proj. Prof. J. Engl. Educ.* **2019**, *2*, 416–420. [CrossRef]
36. Hernández-Ramos, J.P.; Belmonte, M.L. Evaluación del empleo de Kahoot! en la enseñanza superior presencial y no presencial. *Educ. Knowl. Soc. (EKS)* **2020**, *21*, 13. [CrossRef]
37. Rueckert, D.; Pico, K.; Kim, D.; Sánchez, X.C. Gamifying the foreign language classroom for brain-friendly learning. *Foreign Lang. Ann.* **2020**, *53*, 686–703. [CrossRef]
38. Dorion, K.R. Science through Drama: A multiple case exploration of the characteristics of drama activities used in secondary science lessons. *Int. J. Sci. Educ.* **2009**, *31*, 2247–2270. [CrossRef]
39. Purnama, Y.I.; Nurdianingsih, F. The Impact of Higher Order Thinking Skills (HOTS) Instructions in Teaching EFL Speaking Skill from the Perspective of Students' Motivation. *Lingua Cult.* **2019**, *13*, 313–319. [CrossRef]
40. Jassem, K. Teaching gamification. In Proceedings of the 7th International Conference on Education and New Learning Technologies (EDULEARN), Barcelona, Spain, 6–8 July 2015.
41. McConville, J.R.; Rauch, S.; Helgegren, I.; Kain, J.-H. Using role-playing games to broaden engineering education. *Int. J. Sustain. High. Educ.* **2017**, *18*, 594–607. [CrossRef]
42. Shortt, M.; Tilak, S.; Kuznetcova, I.; Martens, B.; Akinkuolie, B. Gamification in mobile-assisted language learning: A systematic review of Duolingo literature from public release of 2012 to early 2020. *Comput. Assist. Lang. Learn.* **2021**, 1–38. [CrossRef]
43. Ishaq, K.; Zin, N.A.M.; Rosdi, F.; Jehanghir, M.; Ishaq, S.; Abid, A. Mobile-assisted and gamification-based language learning: A systematic literature review. *PeerJ Comput. Sci.* **2021**, *7*, e496. [CrossRef] [PubMed]
44. Ramadoss, R.; Wang, Q. Evaluation of a web-based assessment tool for learning grammar at the primary school level. *Int. J. Contin. Eng. Educ. Life-Long Learn.* **2012**, *22*, 175. [CrossRef]
45. Eick, D.; Guikema, J.P. Games as 'Defining Moments' of the College Experience: The Impact of Reacting to the Past in French. *Fr. Rev.* **2019**, *93*, 159–174. [CrossRef]
46. García-Sanz, M. *Fundamentos Teóricos y Metodológicos de la Evaluación de Programas*; Marín, D., Ed.; Routledge: Oxfordshire, UK, 2012.
47. Salán, N.; Rupérez, E.; Illescas, S.; Jorba, J.; Llumà, J.; Rodríguez, D.; Torres, Y. *El Juego de Rol Como Metodología Activa. En M. Mata Montes, Innovación Educativa en Las Enseñanzas Técnicas*; Universidad de Castilla-La Mancha: Ciudad Real, Spain, 2015; pp. 1509–1518.
48. Almenar, V.; Maldonado, M.; Hernández-Sancho, F. Una aproximación Didáctica a la Contratación Bursátil a Través de un Juego de rol en Google-Docs. *Rev. De Docencia Univ.* **2009**, *7*. Available online: https://revistas.um.es/redu/article/view/92601 (accessed on 3 April 2021). [CrossRef]
49. Hernández-Prados, M.A.; Belmonte, M.L.; García-Cantero, I. Validación de un instrumento de recogida de información sobre juegos de mesa en la enseñanza de inglés como lengua extranjera. *Estudios* **2021**, *2*, 1–23. [CrossRef]

50. Huq, A.; Gilbert, D. All the world's a stage: Transforming entrepreneurship education through design thinking. *Educ. + Train.* **2017**, *59*, 155–170. [CrossRef]
51. Thao, T.Q.; Nguyet, D.T.N. Four aspects of English speaking difficulties encountered by tertiary English-majored students. *Soc. Sci.* **2020**, *9*, 53–64. [CrossRef]
52. Chiang, H.-H. Kahoot! In an EFL Reading Class. *J. Lang. Teach. Res.* **2020**, *11*, 33–44. [CrossRef]
53. Rojas, M.A.; Villafuerte, J. The Influence of Implementing Role-play as an Educational Technique on EFL Speaking Development. *Theory Pract. Lang. Stud.* **2018**, *8*, 726–732. [CrossRef]
54. Lynch, T.; Tompkins, J.E.; Van Driel, I.I.; Fritz, N. Sexy, Strong, and Secondary: A Content Analysis of Female Characters in Video Games across 31 Years. *J. Commun.* **2016**, *66*, 564–584. [CrossRef]
55. Sancho-Thomas, P.; Fuentes-Fernández, R.; Fernández-Manjón, B. Learning teamwork skills in university programming courses. *Comput. Educ.* **2009**, *53*, 517–531. [CrossRef]
56. Nieto-Escamez, F.A.; Roldán-Tapia, M.D. Gamification as Online Teaching Strategy During COVID-19: A Mini-Review. *Front. Psychol.* **2021**, *12*, 648552. [CrossRef] [PubMed]
57. Sepúlveda, H. Promoviendo aprendizajes significativos en la enseñanza universitaria de la Historia a través de un juego de roles. *Estud. Pedagóg.* **2020**, *46*, 97–121. [CrossRef]
58. Reeve, J. Teachers as Facilitators: What Autonomy-Supportive Teachers Do and Why Their Students Benefit. *Elementary Sch. J.* **2006**, *106*, 225–236. [CrossRef]
59. Luna, Y.; Conde, A.; Rincón, P. Propuesta Didáctica para el Mejoramiento de la Lectura y Escritura: El Juego de Rol en la Virtualidad. *Rev. Conoc. Investig. Y Educación. CIE* **2021**, *1*, 31–43. Available online: http://revistas.unipamplona.edu.co/ojs_viceinves/index.php/CIE/article/view/4462 (accessed on 5 April 2021).
60. Kirk, G.A. Using role play exercises to enhance communication competence and persuasive communication skills in entrepreneurship programs. *Issues Inf. Syst.* **2018**, *19*, 217–225.
61. Hasmawaty, H.; Syam, H.; Saman, A. Validity, Practicality, and Effectiveness: The Last Step in Development of Entrepreneurship Education Based Role-Playing for Kindergarten. *Univers. J. Educ. Res.* **2020**, *8*, 8092–8101. [CrossRef]
62. Humpherys, S.L.; Bakir, N.; Babb, J. Experiential learning to foster tacit knowledge through a role play, business simulation. *J. Educ. Bus.* **2021**, *96*, 1–7. [CrossRef]
63. Radianto, W.E.D.; Santoso, E.B. Start-Up Business: Process and Challenges in Entrepreneurship Education. *Mediterr. J. Soc. Sci.* **2017**, *8*, 97–110. [CrossRef]
64. An, Y.; Zhu, M.; Bonk, C.J.; Lin, L. Exploring instructors' perspectives, practices, and perceived support needs and barriers related to the gamification of MOOCs. *J. Comput. High. Educ.* **2020**, *33*, 64–84. [CrossRef]

education sciences

MDPI

Article

'The Game of the Sea': An Interdisciplinary Educational Board Game on the Marine Environment and Ocean Awareness for Primary and Secondary Students

Elena Arboleya-García [1,*] and Laura Miralles [2,3]

[1] Department of Education Sciences, University of Oviedo, 33005 Oviedo, Spain
[2] Department of Functional Biology, University of Oviedo, 33006 Oviedo, Spain; lml.miralles@gmail.com
[3] Department of Environmental Genetics, Ecohydros, 39600 Maliaño, Spain
* Correspondence: elenaarboleyagarcia@gmail.com

Abstract: Games are a proven tool for learning at all ages and in many contexts. They increase the attractiveness of learning processes through arousing interest and enhancing motivation, and aid with the development of social skills. Educational games provide teachers with different approaches to teaching. 'The Game of the Sea' is an interdisciplinary board game, specifically designed to teach its players about the marine environment, regardless of their age. Through its 68 sections, coloured according to particular topics and organised as a fish shape, players encounter a wide range of questions and activities. Through playing this game, players acquire a broad knowledge of science, the marine environment and its importance, and literature. The game uses an interdisciplinary approach with question cards on a variety of topics (including maths, physics, biology, chemistry, art, etc.). A total of 222 players (111 children, aged 11–15, and 111 adults, aged 18–72) tested the game. These players were enrolled in different formal and non-formal educational contexts and had different educational backgrounds. For a qualitative analysis of game sessions (participant observation), researchers acted as game moderators and, while doing so, made subtle observations of players playing the game. On top of this, the value of the game, as a didactic tool, was evaluated with a test that players took before and after the game. After playing the game, knowledge of the marine environment, increased in both children and adults, with a slightly higher increase in children. Therefore, 'The Game of the Sea' is suitable for teaching all ages about the marine environment. Further, this game can impart to its players the importance of the marine environment and the importance of protecting this environment.

Keywords: educational game; game-based learning; board game; learning tool; teaching-learning process; interdisciplinary learning; science learning; marine environment; environmental awareness; skills development

Citation: Arboleya-García, E.; Miralles, L. 'The Game of the Sea': An Interdisciplinary Educational Board Game on the Marine Environment and Ocean Awareness for Primary and Secondary Students. *Educ. Sci.* **2022**, *12*, 57. https://doi.org/10.3390/educsci12010057

Academic Editors: José Carlos Piñero Charlo, María Teresa Costado Dios, Enrique Carmona Medeiro and Fernando Lloret

Received: 6 December 2021
Accepted: 13 January 2022
Published: 16 January 2022

1. Introduction

Games are present throughout all stages of life, from childhood and adolescence to adulthood and old age. Moreover, games have been played throughout the existence of human beings. Indeed, playing games is thought to have been essential for the evolution of civilization [1]. Additionally, by being part of social and cultural activities, games can provide important social experiences. Games can be typically described as fun, voluntary, having prescribed settings in time and space and being constrained by rules and procedures (yet being somewhat, unpredictable) [2,3]. Thus, a wide range of social interactions in which people collaborate and/or compete with the aim of achieving determined goals can be considered games [4].

Games can be categorised depending on their purpose: entertainment or education [5]. Educational games have all the characteristics mentioned before, but are specifically designed to achieve learning goals [6,7], and have been proposed as a mean to prevent students failing school [7]. These games try to develop player's cognitive and operational abilities (while reinforcing their social development) through teaching them specific concepts, so that they can understand and expand on these [8]. Therefore, these games should be designed to be teaching materials [9], not just to provide entertainment [10] (although they should be enjoyable too [11]).

Nowadays, educational games are implemented for teaching skills, and academic content, in such different fields as health, business, science, the military, etc., at different levels of education and in different educational contexts (formal, non-formal, and informal) [12,13]. Educational games are sometimes digital [14], though certain scholars think that they should be tangible and face-to-face. Further, non-digital games could supply more, and deeper, interactions among peers and, also, easily allow adaptations of game design to include a wider variety of activities to adapt to different learning styles, or maintain the participant's interest [15]. Gamification is another way in which game elements can be used in education. This does not entail a complete game process, but rather employs whichever elements of games (e.g., badges, game dynamics, etc.) best help players to reach specific goals in their education or improve how they behave with others in non-game contexts [16]. Gamification is employed in fostering students' enthusiasm, by, for instance, providing them with immediate feedback during performance and enhancing recognition of their achievements [17] inside learning contexts.

Both educational games and gamification can be referred to as game-based learning (GBL). GBL uses a learner-centred approach to help learners obtain usable knowledge while developing a wide range of skills [18]. GBL has many benefits. Games have been linked to academic achievement, regardless of the educational stage of the participants [19]. Educational experiences based on GBL allow students to be active participants, rather than passive observers, as they learn through participating in game activities (i.e., problem-solving, making decisions, and reacting to the results of these activities) [20]. GBL gives learners the chance to take risks without real consequences, and reduces their feelings of being exposed as having lower levels of knowledge [21]. Indeed, as games allow players to repeat failed tasks and correct previous mistakes, negative experiences can be transformed into a final success that promotes positive attitudes towards learning through playing [22]. GBL challenges players in a positive way [23], promotes social interactions, fosters attention and concentration, facilitates the construction of long-term memories (through providing continuous and personalized feedback, which also helps tackle misconceptions), and develops emotional skills [24] better than traditional teaching methods [25]. Neuroscience demonstrates further benefits of using GBL. Not only does GBL activate the reward system in the brain, it is also more likely to stimulate retention and engage players toward more effective cognition compared to more traditional methods of education [26,27]. GBL encourages creativity in teaching complex subjects (e.g., sciences) [28]. Games used to teach science subjects can be specifically designed for students' needs so that they can acquire complex knowledge while having fun (thus distracting them from the fact that they are learning [29]).

Despite its many benefits, GBL has some drawbacks. The most common of these is perhaps that games take time and effort, not only to play but also to design, test and implement [18]. This can lead to difficulties in time management and, also, players feeling frustrated if they do not complete the game. Additionally, some players may not take the game seriously. Not only these players may fail to attain the knowledge that they should from the game, teachers might find it hard to determine where they have gaps in their knowledge [21]. An already developed game, aligned with the contents of the *curricula* used in formal education, or the formative program used in informal education, would remove the need for teachers to design and test their own games. Such a game could enable students to reach the same educational goals in less time than traditional methodologies and materials [30].

Board games have been the most popular kind of non-digital games for centuries and, in all age groups, are still the kind most played by people [31]. Board games are also traditionally used, in GBL, for developing academic knowledge and cognitive skills, and have a number of advantages that aid with this. They can address different learning styles [20,32], contents and procedures to be adapted for personalised sessions [33]. They allow players to learn by doing, foster hands-on skills, and promote self-confidence and self-learning [34,35]. They can have clear rules that make it easy to understand, initiate, and sustain game play at an adequate rhythm [36]. They use a combination of tangible materials, turn-taking modes, and face to face interactions among peers or teams [37]. They create a non-threatening environment that supports mutual learning [29] since they provide opportunity for players to receive feedback or clarification, have discussions, and reflect on the game [38], which benefits both peers and game moderators [39]. They involve competition, which can be highly positive, if this motivates players to cooperate with each other and do their best in the game [40]. Nevertheless, success in educational games is based more on aptitude and knowledge than on competitiveness. The above suggests board games to be a powerful educational tool for all ages, across educational contexts [12], in alignment with the long-life learning concept, which implies learning with, and from, other people [20]. Evidence for the success of board games as educational tools include their already frequent use in different educational contexts and in teaching many different subjects. When introduced in university contexts, board games were not considered a childish activity or a waste of time [41]. Such games have yielded excellent results at Undergraduate and Master's levels [42,43]. At the other end of the academic spectrum, playing games is the most frequent learning activity in Elementary and Primary Education [28]. Among the many different subjects taught with board games [44] are architecture [45], astronomy [18,46], biochemistry [47], chemistry [35], ecology [48], electronical engineering [49], environmental sciences [50], healthcare sciences [29,51,52], palaeontology [53], pharmacy [54], chemical engineering [55], and engineering [56].

In this sense, board games could help people better understand how the marine environment and humanity influence each other. This is ocean literacy, conceptualized as 'an understanding of the ocean's influence on citizens and citizens' influence on the ocean' [57]. Accordingly, board games could be used as an effective communication tool to generate environmental awareness [58]. This is important as, with this understanding, people can better communicate information on the marine environment and make conscientious decisions regarding this [59,60]. Through playing board games, players could learn about specific concepts such as sustainability problems that marine ecosystems currently face, as well as how to restore and protect the marine environment. Such education should be present for all ages [61], although children are most likely to change their behaviours in response to it [62]. A better understanding of ecosystems comes from scientific knowledge but arts (in its broader conceptualization as paintings, films, documentaries, etc.) also have the capability to engage people and foster environmental awareness [63].

Here, we present 'The Game of the Sea', a game, suitable for any educational context, regardless of the players age, which focuses on specific *curricula* contents that can lay the foundation for a deeper understanding of the marine environment. 'The Game of the Sea' has an interdisciplinary approach, which integrates information on the marine environment from different disciplines. This differs from a multidisciplinary approach as, while the latter also involves different disciplines, each discipline provides a specific perspective, typically resulting in poor, or null, connections between them [64].

Creating an attractive educational game, which can be successfully used for teaching science, and raising awareness on environmental issues, while holding the players' attention for a long-time, can be difficult [25]. Nevertheless, the development of such games should be encouraged, as they promote the development of important skills. These skills include critical thinking (if the game requires scientific reasoning, decision making and problem solving), collaboration (if players need to work together), creativity (if players need to think outside the box), and communication (if players need to share ideas) [6,65,66]. On top of this, educational games strengthen students' autonomy, self-confidence, and self-esteem. Thus, 'The Game of the Sea' was conceived to teach and learn about marine environment, based on both popular quizzes and board games with a background of sciences such as physics, biology, mathematics, geology, chemistry, or literature.

The 'Game of the Sea' was specifically designed for rising citizen awareness about marine conservation while enjoying and learning. The learning goals of this game are: (1) To enable students to achieve learning objectives (based on the official *curricula* of Spanish Compulsory High School Education) in terms of learning about the marine environment. (2) To foster collaborative learning, regardless of age or educational background. (3) To raise awareness about critical situations regarding our marine environment, and the need to preserve this environment. The learning objectives of the game are for players: (a) To recognise organisms from marine ecosystems. (b) To identify invasive marine species and their environmental consequences. (c) To relate geological concepts to marine phenomena. (d) To apply laws of mathematics, physics, and chemistry to understanding the marine environment. (e) To understand how information about the marine environment that they learnt in schools applies to their daily life. (f) To analyse literary works related to the marine environment. (g) To discuss and compare information about each topic involved in the game. (h) To produce a wide variety of creative works focused on the marine environment. We designed the game based on three main questions that need to be taken into account in educational game design [67]: (1) What are the learning objectives. (2) What materials are needed to reach the learning objectives (i.e., what are the learning contents). (3) How can students learn while playing the game (i.e., what is the learning methodology). To answer to these questions, we trialled the game in different places in Asturias, a coastal region in Northern Spain. People from formal, non-formal, and informal educational contexts, and between the ages of 7 and 72, took part in these trial game play sessions with satisfactory knowledge acquirement results.

2. Materials and Methods

2.1. Game Materials

'The Game of the Sea' is a dice-based game inspired by the popular 'Trivia' game model (Figure 1). Playing materials have been specifically designed by authors for this educational purpose. Learning objectives, learning contents, and learning methodology were previously defined and taking into account before designing the game. Learning objectives were enumerated in a list and materials were designed accordingly to reach all of them. Once the goals were defined, learning contents and learning methodology were designed to meet the games learning goals and objectives (listed earlier). The game included elements of physics, biology, mathematics, geology, chemistry, and literature in an interdisciplinary approach, in which different disciplines are used together to improve overall understanding. The game was registered in Spain under the copyright reference 05/2017/329.

'The Game of the Sea' consists of a board on which is printed a fish shape (another marine related shape—an octopus, star fish, or a whale, for instance—could be used instead), divided into 68 sections coloured blue, yellow, red, or green. There is also one additional section where all the individual team pieces are placed, at the start of the game. Inside the shape are four rectangles (blue, yellow, red, and green) on which cards of matching colour are placed.

Figure 1. Playing materials needed to play 'The Game of the Sea': game board, question cards, dice, player's pieces, scoreboards, and circular stickers.

The cards (n = 80) are the learning content of this game and contain a variety of simple activities (e.g., multiple-choice questions, problem solving, filling gaps, comparing photographs, etc.) to maintain the players' interest. These cards were carefully designed to be easily readable and comprehensible, and are coloured based on which part of the European educational syllabuses they aimed to teach about:

- Blue: marine environments, water properties, marine invasive species and the threats they present to marine ecosystems.
- Red: elements from popular Spanish culture and literature, such as poems or tongue twisters, as well as artistic creations (all illustrating the relationship between the arts and the marine environment).
- Green: simple experiments and questions on Biology, Geology, Physics, Chemistry and Mathematics; all linked to the marine environment.
- Yellow: cards of this colour did not refer to the educational syllabus, but rather contained light-hearted activities designed to entertain and relax participants.

Additionally, required to play the game are one dice, game pieces, scoreboards, and circular stickers. Game pieces (e.g., seashells, painted in different colours) are used to represent each player or team moving along the board. Scoreboards are in the shape of a wave formed by several circles. Each time a player scores a point they place a sticker in one of the circles of the wave score board.

2.2. Rules of Play

The most dynamic option to play 'The Game of the Sea' is in small groups of two to six players, although the game can be also played individually. The first step is to make teams and get a scoreboard and a game piece per team. Each team puts their piece in the initial square. Then, a player from each team rolls the die. The team with the highest number starts playing by moving their piece as many squares as the number on the die indicates.

Next, one member of the team takes a card of the same colour as the colour of the section their piece lands on. The text on the card should be read aloud, clearly, ensuring the rest of the players (even those from other teams), can understand what is read. In this way, if the first team does not complete the activity on the card, other teams have the opportunity to do so and get extra points.

Players have five seconds to answer the question or complete the activity on the card. This ensures the game has good rhythm and helps players follow it easily. If extra time is allowed (for another kind of activities, such us scientific experiments), this is indicated on the card. Regarding those cards that contain scientific experiments, the team should first choose an answer and then carry out the experiment to test this. When a team scores, they get a sticker to complete the wave printed in their scoreboard. The game will finish when a team succeeds in completing the wave with all stickers.

As a recommendation, the game should have a moderator. This person can not only explain and enforce rules and game timing [58], but also, as they know the solutions to the cards, provide deeper explanations of these and help players come up with solution. However, the moderator ought to allow participants to first try to explain card contents, and solutions, to their team players, before explaining these themselves. Moderators should also encourage collaborative learning and aim to ensure that there is more communication among teams than between the teams and themselves.

2.3. Players

Pilot studies of how the game could function (duration, audience, etc.) were carried out in two different samples: children from 7 to 15 years old during the educational event on marine environment 'Aula del Mar' and in 'El Pez Escorpión' surf school (both in Salinas, Asturias, Spain), and adults from 24 to 50 years old from the International Workshop ALERTOOLS (Avilés, Asturias, Spain). The principal aim of these pilot studies was to identify possible limitations regarding materials, contents, or procedures [68]. Furthermore, from the pilot study we identified six questions which were used to develop a test to assess the success of our game (see '2.6. Game assessment'). Game sessions in the pilot study and in later assessment lasted between one to one and a half hours, approximately (there was no set time restriction).

After the game was refined based on the pilot studies, two further samples were selected to assess the game as a didactic tool. We had one children sample and one adult sample, thus we could check the appropriateness of the game for different age groups. These samples were selected intentionally [69], according to the interest of instructors from each educational context that the samples came from. One of the samples 'children' (Table 1) was formed by 111 students, between 11–15 years old, from two high schools from Asturias (Spain): IES Escultor Juan de Villanueva (Pola de Siero-Asturias) and IES Salinas (Salinas-Asturias). The other sample 'adults' (Table 2) was composed of 111 people between 18 and 72 years old. These were either university students from Elementary Teaching Degree, High School Teaching Master of the University of Oviedo, who came from different locations, or adults who had enrolled in Lifelong Learning education programmes at the University of Oviedo (Evolution Club) who were from Oviedo and Avilés (Asturias). All participants (n = 222) had different educational backgrounds, thus enabling us to assess the effectiveness of this didactic tool on people with a variety of different academic levels and experiences. We tested the game six times in children and six times in adults, therefore we collected data from 12 game sessions in total.

Table 1. 'Children'. Sample formed by people between 11–15 years old.

	IES Escultor Juan de Villanueva	IES Salinas	N (%)
Female	44	19	63 (56.8)
Male	34	14	48 (43.2)
			111

Table 2. 'Adults'. Sample formed by people older than 18 years.

	Elementary Teaching Degree	High School Teaching Master	Evolution Club	N (%)
Female	20	21	18	59 (53.2)
Male	10	29	13	52 (46.8)
				111

If the players were children, high school science teachers also took part in the sessions. Although they performed a secondary role during the gameplay sessions, their involvement was highly valuable because they could illustrate to their students how material on the game cards linked to their *curricula* contents.

2.4. Ethics Statement

This study adhered to the European Code of Conduct for Research Integrity. All players were informed that all data would be collected and used only for research, and gave informed consent for this. For children and teenagers under 18, their parents signed a participation permit, and their headmasters and teachers gave us permission to play the game for several sessions that fitted into their high school timetable. Adults from Elementary Teaching Degree, High School Teaching Master and Evolution Club, played the game as volunteers.

2.5. Qualitative Analysis of the Game

Participant observation was the qualitative research technique employed in different stages of 'The Game of the Sea' development. In particular, it had a relevant implication in those stages referred to test the game during the pilot study first, and its implementation with the sample selected after. This technique consists of the researchers being part of the observed situation. The researchers had access to the information about how phenomena took place, without interactions, in contrast to external observation processes. In this sense, information collected was more accurate than information collected through more obvious external observations [70–72], in which players may have felt scrutinized, would have been.

Researchers obtained qualitative data on the whole gameplay process of 'The Game of the Sea'. The researchers acting as the moderators collected this data by observing the participants as they played the game. They were subtle about doing so, helping players to relax and act naturally. The moderators noted the different ways that players perceived the questions and instructions on the cards and interacted with their peers to respond to these. By doing so, the moderators could not only determine whether game's contents and methodology enabled players to achieve the learning objectives of the game, but also whether collaborative learning took place. Participant observation provided an insight into the whole gameplay process. Data and information collected were registered through field notes.

The analysis of the whole process was focused on learning objectives, learning contents, and learning methodology. The participant observation technique yields interesting information regarding perception of the contents of the questions, and the own answer given to each question by players. Moreover, participant observation contributes to examine the internal team process to choose a response, and also the explanations, discussions, and reflections generated during the gameplay process.

2.6. Game Assessment

Based on our pilot studies, we created a brief test which, in later game play sessions, we gave to players before ('pre-test') and after ('post-test') playing 'The Game of the Sea' to verify if players achieved the learning objectives of the game and to evaluate if this game was an effective didactic tool.

The test consisted of six questions where the player chose what they thought was the correct answer from multiple options. Players could also indicate if they were unaware of the answer. The six questions related to three topics covered in the game: Biology, Physics, and Literature (Table 3). The test was checked by 10 people, before implementation as a game assessment tool, to ensure clarity and consistency between questions and answers. A time limit of five minutes was given, on both occasions, for the test. Players were not told about the post-test to avoid them attempting to memorise correct answers from the pre-test.

Table 3. Test used to assess the success of the Game of the Sea in teaching our learning objectives.

Biology	**Q1. Invasive alien species, are harmful to . . .**	**A. Society, economy, and ecology.** [1]
		B. Only to ecology.
		C. They are not harmful.
		D. I do not know.
	Q2. What kind of animal are cetaceans?	A. Fish.
		B. Mammals. [1]
		C. Birds.
		D. I do not know.
Physics	Q3. Where does the speed of a sound go faster?	A. In the water. [1]
		B. In the air.
		C. The sound speed is the same in both, water, and air.
		D. I do not know.
	Q4. If we have two balloons, one with air and the other one with some water, and we heat them, which one will blow out first?	A. The balloon only with air. [1]
		B. The balloon with some water.
		C. Both will blow out at the same time.
		D. I do not know.
Literature	Q5. The follow poem was written by José de Espronceda, what is its title? (We read a piece of the poem)	A. The song of the pirate. [1]
		B. The sailor and his sailing boat.
		C. The sea and the grouper.
		D. I do not know.
	Q6. What animal has an odd number of arms but not calyx?	***A.*** *An octopus.*
		B. A sea star. [1]
		C. *A sea lily.*
		D. I do not know.

Q indicates a question. A–D are the potential answers the players can choose between. [1] The correct answer for each question is highlighted in bold style font.

Data was collected from the five questions Q1–Q5 on pre- and post- test, and results were coded and tabulated. Q6 was not included in the final study tests because no differences were found between tests on both pilot studies. Researchers found through their participant observation that Q6 did not provide any information, and answers were the same before and after the game. Responses to the tests (Q1–Q5) were classified into three groups: 'success' to cluster all correct answers, 'wrong' to group all wrong responses, and 'unaware' that represent all the 'I do not know' answers.

Descriptive analysis, percentages, frequencies, and statistical analyses were calculated with IBM SPSS Statistics programs to obtain a more complete understanding of this [73], and check whether the patterns we observed were mathematically supported. The non-parametric test 'Pearson chi-square of independence' was considered the most appropriate to analyse frequencies from two independent samples [74]. This statistical test was used to determine whether the number of correct, and unaware answers differed between the pre- and post-tests. The analysis was first done on adults and children separately and then in adults and children combined. We used a significance threshold of $p < 0.05$.

Finally, the triangulation of the qualitative and quantitative methods employed was done. This research strategy provides an increment of the validity of data collected and could give a relevant interpretation of the information available [75].

3. Results

The game was played in 12 sessions, 6 sessions for each group. Every game session lasted approximately between an hour and an hour and a half. During gameplay sessions players, both age groups showed motivation, engagement, and enjoyment during and after the game.

3.1. Qualitative Information

3.1.1. Learning Objectives of the Game

From observations made as moderators, we verified that all the questions and contents associated with each learning objective were addressed in each game session. Table 4 shows how the questions in the game related to the learning objectives, and classifies them according to the observed level of difficulty encountered by the players during the game sessions. Below, a description of how both samples (i.e., children and adults) performed during the game in terms of different learning objectives.

Table 4. How questions in the game related to learning objectives.

Learning Objective	**Difficulty Level of Question**	
	Low	**High**
(a) To recognise organisms from marine environments.	QA1. Sea sponges are: A. Animals. [1] B. Algae. C. Plants.	QA2. What group does the seahorse belong to? Participants should choose one of the following options: A. Fish. [1] B. Shellfish. C. Jellyfish.
(b) To identify invasive marine species and their environmental consequences.	QB1. In Asturias, only animals are invasive species: A. True. B. False. [1]	QB2. The scorpion fish (*Trachinus draco*) is an invasive species in the Asturian marine environment, but it is very similar to the red scorpion fish (*Scorpaena scrofa*), a native species. Would you be able to identify both of them in these pictures? *Moderators provide two pictures, one of each fish species and team members should discuss to correctly identify each one.*
(c) To relate geological concepts to marine phenomena.	QC1. In the Picos de Europa National Park you can easily find remains of marine living beings: A. True. [1] B. False.	QC2. Are there mountain ranges in the depths of the ocean? Participants should choose one of the following options: A. Yes. [1] B. No.

Table 4. *Cont.*

(d) To apply laws of Mathematics, Physics, and Chemistry to understanding the marine environment.	QD1. How can you make a coin fall into a bottle if it is balanced on a thin stick over the opening? You cannot touch the coin or the stick. A. Dropping water on the coin. [1] B. Blowing the coin. C. Waiting for an earthquake which would shake the bottle, the coin, and the stick. *Moderators provide all materials and instructions needed to participants in order to they carried out on their own the scientific experience successfully and checked the correct answer.*	QD2. If we put a candle in the centre of a plate with water, and then we cover it with a glass, what will happen? A. The water will be drawn into the glass. [1] B. The candle will melt totally. C. The glass will burst. *Moderators provided all materials and instructions needed to players so that they could carry out the scientific experiment successfully and then checked they got the correct answer.*
(e) To understand how information about the marine environment that they learnt in schools applies to their daily life.	QE1. The tides are due to: A. The movement of the rest of the planets. B. The attraction between the Earth and the Moon. [1] C. The energy sent by the Sun.	QE2. It is 8 a.m. and in Avilés there is a high tide. According to the forecast, at 20:15 there will be a high tide again. At what time will there be a low tide? A. **At 13:50.** [1] B. At 16:10. C. At 18:30.
(f) To analyse literary works related to the marine environment.	QF1. Which legendary creature does the giant squid correspond to? A. Moby Dick. B. Kraken. [1] C. Flipper.	QF2. The following piece of Espronceda's poem, 'The pirates' song', has lost some words. Can you fill in the gaps in less than 20 s? Moderators provided a piece of paper where the poem was presented with six blank gaps and a short list of words. Players had to choose the correct words from the list and fill in the gaps.
(g) To discuss and compare information about each topic involved in the game.	QG1. Oceans cover: A. A half (1/2) of the surface of the Earth. B. A quarter (1/4) of the surface of the Earth. C. Two thirds (2/3) of the surface of the Earth. [1]	QG2. There are millions of tons of plastic and other rubbish which floats in the oceans. Can this carry invasive species to new locations? A. True. [1] B. False.
(h) To produce a wide variety of creative works focused on the marine environment.	QH1. Each member of the team has to make a paper boat with a piece of newspaper. *Moderators provide some pieces of newspapers to the team which has less than a minute to complete their creations.*	QH2. All the members of the team together act out a topic written on the card and the other teams guess what the topic is. The performing team only scores if the f other team guesses their topic correctly, other teams score by guessing the correct topic. *Moderators provide some pieces of papers with topics on, the performing team chooses one without looking at the topics. Topics could include Asturian traditions about whale hunting, the birth of the seahorse, and so on.*

[1] The correct answer is highlighted in bold style font.

(a) To recognise organisms from marine ecosystems

Marine organisms were fascinating to most people playing the game, regardless of their age, although knowledge and understanding of these organisms varied considerably. For instance, sea sponges were easily identified as animals (Table 4; QA1) by both samples, whereas some players did not know which groups cetaceans, or seahorses, belonged to (Table 3, Q2; Table 4; QA2). This is despite sea sponges, cetaceans, and seahorses- all being common in the Asturian marine ecosystems. Children could explain to each other that cetaceans were mammals; however, the fact that seahorses were fish needed clarification from the moderator.

(b) To identify invasive marine species and their environmental consequences

There are plenty of invasive species in the Asturian region, thus we expected players to be aware of them. Players were aware that invasive species could be both plants and animals (Table 4, QB1). However, differentiating between a common non-invasive edible fish (*Scorpaena scrofa)* and an invasive non-edible one (*Trachinus draco*) was almost impossible for children. This was less difficult for adults (Table 4, QB2). In the children sample, group teachers and/or moderators provided explanations about the differences between both species. Within the adult sample, some people were able to identify the non-invasive species because they had seen it at the fishmongers. In fact, in one of the adults' game sessions, a retired fishmonger explained the characteristics of both species to the other players.

(c) To relate geological concepts to marine phenomena

Participants of all ages knew about the Cantabrian range, where Picos de Europa National Park is located, in Asturias. Most of the players were aware of the existence of marine fossils in these mountains (Table 4, QC1). However, only a few were able to link this sort of land formation with ocean ridges despite this being part of the school *curricula* (Table 4, QC2).

(d) To apply laws of Mathematics, Physics, and Chemistry to understanding the marine environment

Questions based on this learning objective were the most demanding for players in both samples. Of these, those the players found hardest were theoretical questions (e.g., Table 3, Q3) and some questions that involved scientific experiments (Table 4, QD2). Children did better than adults in some questions involving scientific experiments (Table 3, Q3; Table 4, QD1). Providing clear and accurate explanations, for these questions, for their peers was as challenging for children as it was for adults. So, moderators often needed to do this. In all cases, players were pleased to take part in experiments, under supervision, and were delighted with the results observed.

(e) To understand how information about the marine environment that they learnt in schools applies to their daily life

Players understanding of marine phenomena observed in daily life was sometimes less than expected. For example, both children and adults showed poor understanding of what causes tides (Table 4, QE1). Further, only one adult group (that contained a seaman) was able to calculate the timing of the tides (Table 4, QE2). This was despite that there are two high and two low tides and a difference of approximately six hours between a high and low tide is taught at the first level of High School.

(f) To analyse literary works related to marine environments

Players from both samples remembered a literary work featured in this game called 'The pirates' song', from their elementary education (Table 4, QF2). Despite experiencing positive emotions upon remembering this song, players still found it difficult to identify the name of the author and the title of the poem, and also to fill in gaps in its paragraphs. Players found information from more recent literary works easier to recall.

(g) To discuss and compare information about each topic involved in the game

Climate change and how this affects the Earth, in particular the oceans, was discussed by both children and adults. The question relating to how much of the surface of the Earth is covered by oceans was answered successfully in almost all cases (Table 4, QG1). This led several players to comment on the risks of ice melting and the subsequent rise in sea levels. Furthermore, both groups entered into discussions about invasive marine species. However, nobody was able to identify floating rubbish, or the use of vehicles (such us merchant ships), as vectors by which invasive species could enter the marine ecosystem (Table 4, QG2).

(h) To produce a wide variety of creative works focused on the marine environment

Team creativity was not evident in some groups (Table 4, QH2). We found that adults (especially women in their seventies) tended to be more creative and got more involved in creative activities than children. Nevertheless, all players enjoyed using pieces of newspaper to make boats, for instance. Although some children did not know how to do this, they were taught how by their peers.

3.1.2. Collaborative Learning

Players communicated successfully with their peers, which led them acquiring knowledge from the game.

Initially, children were more likely to interact when there was a moderator present. However, as the session progressed peer interaction within the teams increased. This may have been due to the reward of extra points when team members could provide a correct answer to the question.

Adults performed somewhat differently to children. This is possibly due to their different academic and occupational backgrounds. A high level of peer interactions, both within and across the adult teams, was observed. In this case, moderators were only required to clarify concepts, keep the game moving along, or provide materials needed to solve questions.

3.2. Game Assessment Tool

Data collected from pre- and post-test is presented in Table 5. How the number of 'correct', 'unaware' and 'wrong' answers changed between the pre- and post-tests is analysed in the next section.

Table 5. Absolute frequencies of correct, wrong and unaware answers for the questions used in our game assessment test.

			Children		**Adults**		**Total**	
			Pre-Test	**Post-Test**	**Pre-Test**	**Post-Test**	**Pre-Test**	**Post-Test**
Biology	Q1	Correct	28	99	87	110	115	209
		Wrong	28	7	14	1	42	8
		Unaware	55	5	10	0	65	5
	Q2	Correct	23	85	61	90	84	175
		Wrong	63	24	43	20	106	44
		Unaware	25	2	7	1	32	3
Physics	Q3	Correct	10	107	38	105	48	212
		Wrong	96	4	68	6	164	10
		Unaware	5	0	5	0	10	0
	Q4	Correct	93	107	63	107	156	214
		Wrong	17	1	40	4	57	5
		Unaware	1	3	8	0	9	3
Literature	Q5	Correct	36	72	88	103	124	175
		Wrong	56	34	12	8	68	42
		Unaware	19	5	11	0	30	5

3.2.1. Analyses of Correct Answers

Children only had one question in the pre-test (Q4), in which they had a frequency of correct answers higher than 50% (93 correct answers mean 83.78%; Table 4). In adults, the frequency of correct answers in the pre-test was higher than 50% for all questions, apart from Q3 (for which the frequency of correct answers was 38, it means 34.23%; Table 4).

In both age groups, the post-test mean frequency of correct answers was significantly higher than the pre-test mean frequency of correct answers (Table 6). Standard deviation was lower in the pre-test than in the post-test, for both samples, and, in both tests adults had more homogenous answers than children (Table 6).

Table 6. Descriptive statistics for frequency of correct answers in the pre-tests and post-tests.

	Children		**Adults**		**Total**	
Test	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Pre-test	59.78	33.10	72.54	17.11	67.94	24.87
Post-test	95.97	12.94	103.46	6.63	99.89	10.81

Significant differences between pre-test and post-test in each subsample and within each question were detected. Children differences between pre-test and post-test were highly significant (Chi-square = 60.848, *p*-value = 0.000). Correct answers increased from less than 30% in the pre-test, to over 70% in the post-test (Table 7). In adults, Chi-square also yields significant differences between pre-test and post-test correct answers. (Chi-square = 15.711, *p*-value = 0.003). The increment between the pre- and post-test was from 39.6% to 60.4% (Table 7).

Table 7. Correct answers cross table: percentage (%) of correct answers within each question and whole tests.

	Q1		**Q2**		**Q3**		**Q4**		**Q5**		**Total**	
Test	**CH**	**AD**	**CH**	**AD**	**CH**	**AD**	**CH**	**AD**	**CH**	**AD**	**CH**	**AD**
Pre-test	22.0	44.2	21.3	40.4	8.5	26.6	46.5	37.1	33.3	46.1	28.8	39.6
Post-test	78.0	55.8	78.7	59.6	91.5	73.4	53.5	62.9	66.7	53.9	71.2	60.4

CH: children; AD: adults.

The question on which both age groups achieved the highest scores in the post-test (and the highest increase in scores between pre- and post-tests) was Q3 (Table 7). There were also significant differences in the frequency of correct answers between the pre-tests and post-tests, for both age groups, for Q1 (Chi-square = 16.495, *p*-value = 0.000), Q2 (Chi-square = 10.483, *p*-value = 0.001), Q3 (Chi-square = 13.891, *p*-value = 0.000) and Q5 (Chi-square = 4.613, *p*-value = 0.032) but not for Q4 (Chi-square = 3.359, *p*-value = 0.067).

3.2.2. Analyses of Unaware Answers

The frequency of unaware answers was significantly lower than the frequency of correct answers in general. Descriptive statistics (Table 8) show that unaware answers were more frequent in pre-test than in post-test and this pattern was more pronounced in children than in adults. First, children were more likely to give an unaware answer for each question compared to adults (Table 8). Second, children had a larger decrease in the number of unaware answers between pre- and post-tests than adults, this decrease was significant for children (Chi-square = 18.116, *p*-value = 0.001), but not for adults (Chi-square = 4.354, *p*-value = 0.360).

Table 8. Unaware answers descriptive statistics in each test and subsample.

	Children		**Adults**		**Total**	
Test	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Pre-test	38.45	18.02	8.76	2.05	30.11	20.33
Post-test	4.21	1.2	1.00	-	4.00	1.41

Q1 and Q5 were the questions which both age groups were most likely to give an unaware answer to (Table 4). For Q4, the number of unaware answers increased between the pre- and post-tests, from one unaware answer in the pre-test to three unaware answers in the post-test (Table 4).

Overall, considering both samples together unaware answers decreased sharply between the pre- and post-tests (Table 9). However, there were significant differences in the frequency of unaware answers between the pre-tests and post-tests, for both age groups, only for Q4 (Chi-square = 8.000, *p*-value = 0.005), but not for Q1 (Chi-square = 0.897, *p*-value = 0.343), Q2 (Chi-square = 0.204, *p*-value = 0.651), and Q5 (Chi-square = 2.674, *p*-value = 0.102).

Table 9. 'Unaware' answers cross table: percentage (%) of correct responses within each question and whole tests.

	Q1		Q2		Q3		Q4		Q5		Total	
Test	**CH1**	**AD**	**CH**	**AD**	**CH**	**AD**	**CH**	**AD**	**CH**	**AD**	**CH**	**AD**
Pre-test	91.7	100.0	92.6	87.5	100.0	100.0	25.0	100.0	79.2	100.0	87.5	97.6
Post-test	8.3	0.0	7.4	12.5	0.0	0.0	75.0	0.0	20.8	0.0	12.5	2.4

CH: children; AD: adults.

3.2.3. Analyses Considering Each Topic Separately

Knowledge increase occurred in all the three topics covered by the test (Figure 2). Children's knowledge increased substantially in Biology and Physics, and they show considerably higher scores in the post-test, compared to the pre-test, in the literature. Adults showed a high and similar post-test percentage of correct answers regarding Physics questions compared to the children.

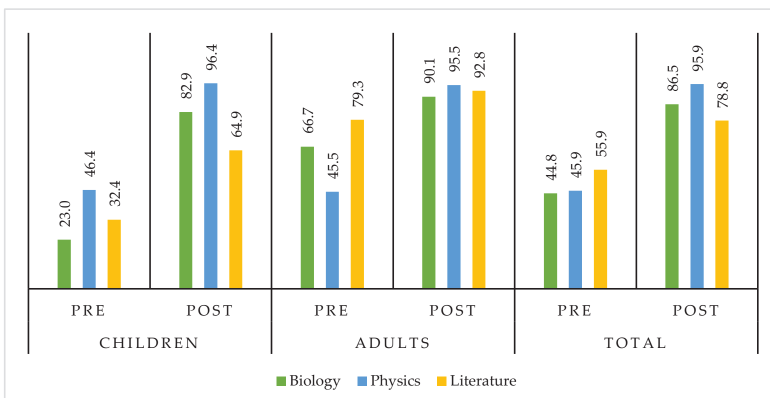


Figure 2. Knowledge (%) in the three main topics of 'The Game of the Sea': Biology, Physics, and Literature, comparing pre- and post- tests data of both studied samples (children and adults).

Unaware answers decreased in each age group and in each topic (Figure 3). The sharpest decrease in unaware answers, particularly in children, was in Biology. There was also a decrease in the number of unaware answers in terms of Literature questions. More adults gave unaware answers to Physics question in the pre-test compared to children, but were less likely to do so, compared to children, in the post-test. Overall, adults were less likely than children to give an unaware response in the whole post-test.

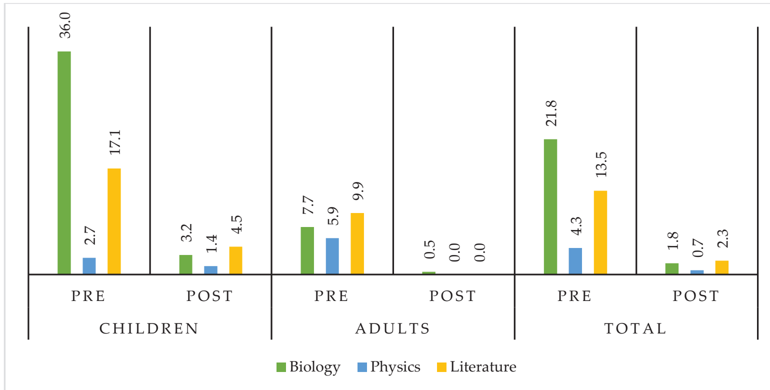


Figure 3. 'Unaware' percentage (%) in biology, physics), and literature in each subsample (children and adults), before and after playing 'The Game of the Sea'.

4. Discussion and Conclusions

'The Game of the Sea' gave players the opportunity to acquire knowledge on a wide range of topics related to the marine environment. Sometimes scientific communication is not clear and/or not accessible enough to citizens [76]. Board games can, therefore, play an important role in scientific communication by simplifying complex scientific concepts, or environmental issues, to make the salient points understandable to citizens [8,33,37,58]. As well as being educational, some of the cards used in our game appeared to be thought-provoking [77], creating much discussion among players, who were regularly surprised by their contents, and inspiring them to find out more about specific topics. Two of the most discussed topics were marine invasive species and the sea level rise.

Previous studies suggest that game-based learning (GBL) engages participants and significantly increases knowledge [18,78,79]. 'The Game of the Sea' supports these findings, further demonstrating that board games, and GBL in general, can be important in educational contexts. Game elements which were specifically designed for 'The Game of the Sea' (such as an overly sized die, seashells as playing pieces, or sticker points) made the game more enjoyable for players. This, in turn, made players more self-confident while playing [53], which contributed to them achieving the learning objectives of the game [52]. Different participants played the game with different attitudes, which often changed over the course of the game. At the start of the game, players often showed high levels of competitiveness towards each other, in each sample. It decreased as the game progressed and players increasingly worked together to find the right solutions. This working together attitude produced collaborative learning which certainly contributed to the game success in improving players' knowledge about marine ecosystems [35], and showed that this game could be an efficient didactic tool for both children and adults [80,81]. As well as fostering collaborative learning, the discussions and interactions that took place in the game, generated by the game cards fostered other important skills, such as critical thinking, scientific reasoning, decision making, problem solving, collaboration, and creativity.

As well as being a tool for teaching about the marine environment, 'The Game of The Sea' has other positives attributes. First, all the materials for the game are accessible on request, can be handmade, and can be replicated at a low cost (less than EUR 20). This makes 'The Game of the Sea' an easy to replicate and affordable, didactic tool, available to different educational levels and situations. Second, the cards used in this game are very versatile, allowing the contents of the game to be adapted for use in various situations, without modifying the format of the game. This, along with that the game is determined by how players interact, increases its unpredictability, making it more interesting.

Pre- and post-test questions were used to verify if players achieved the learning objectives of the game. What players got out of the game, in terms of knowledge acquisition, could have been influenced by their age and background (both academic and occupational). Although both age samples showed significant increases in the number of correct answers between pre-test and post-test results, this was more pronounced in children than in adults. A potential explanation for this is that all the information contained in the game cards is taught in official educational programs in Europe. Thus, adults would have finished their education on these topics while children may not have yet. Therefore, this game could be considered as a noteworthy didactic tool (in terms of knowledge acquisition) for an interdisciplinary approach of those scientific contents related to marine environment from the official *curricula* of Spanish Compulsory Elementary, Middle and High School Education.

Players did not necessarily find different questions on the same topics to be of similar difficulty. For example, children found Q4 (If we have two balloons, one with air and the other one with some water, and we heat them, which one will blow out first? R4: The balloon only with air) the easiest to answer in the pre-test, and adults found Q3 (Where does the speed of a sound go faster? R3: In the water) the hardest, despite both questions being Physics questions. One explanation for why players were much more likely to know the answer to Q4 than Q3 is that Q4 is more easily tested with an experiment than Q3. There was little increase in the number of correct answers in Q4 between pre- and post-tests (most players got it right both times), which suggests that players may have already seen this experiment, or a similar one, prior to playing the game. When children and adults were considered together, Q3 showed the greatest increase in the number of correct answers between pre- and post-test. Peer interaction contributed to this, Q3 was, overall, one of the most clarified questions. In general, the discussions which took place during gameplay among players and with moderators, allowed for clarification of misconceptions, thus enabling players to successfully reach the learning objectives of the game [39].

Through playing 'The Game of the Sea' players improved their interdisciplinary knowledge on the marine environment and critical situations facing this environment. Thus, the game achieved its 3 main goals: (1) To enable students to achieve learning objectives (based on the official *curricula* of Spanish Compulsory High School Education) in terms of learning about the marine environment. (2) To foster collaborative learning, regardless of age or educational background. (3) To raise awareness about critical situations regarding our marine environment, and the need to preserve this environment. Achieving this third goal was especially important. Nowadays, policies to protect the marine ecosystems are not well enforced/often overlooked [82], and politicians and lawmakers appear to have little concern for the marine environment. Thus, marine ecosystems increasingly rely on the general public to help protect and preserve them. Consequently, raising public awareness of the situations our marine environments face (e.g., through board games, which can simultaneously educate and entertain people from many walks of life [63]) can positively contribute to achieving marine conservation objectives [83,84]. In this study 'The Game of the Sea', was shown to facilitate learning [13] about the marine ecosystems, thus enhancing awareness, in all ages, of the importance of preserving this environment.

5. Patents

'The Game of the Sea' has been registered at Intellectual Property Registry of the Principality of Asturias in Spain with the copyright reference 05/2017/329.

Author Contributions: Conceptualization, E.A.-G. and L.M.; methodology, E.A.-G. and L.M.; validation, E.A.-G. and L.M.; formal analysis, E.A.-G.; investigation, E.A.-G.; resources, E.A.-G.; data curation, E.A.-G.; writing—original draft preparation, E.A.-G.; writing—review and editing, E.A.-G. and L.M.; supervision, L.M. 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. The protocol was approved by the high schools IES Escultor Juan de Villanueva and IES Salinas, and the University of Oviedo where the research took place.

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 acknowledge 'Surf, Music & Friends Festival' and the surf school 'El Pez Escorpión', in Salinas (Asturias, Spain) the opportunity to play and test the game as a pilot study therein. It was also played in ALERTOOLS International Workshop. We have collected data thanks to the interest in the game of teachers and students from IES Escultor Juan de Villanueva and IES Salinas; students from Elementary Teaching Degree, High School Teaching Master of the University of Oviedo, and participants in Evolution Club of University of Oviedo. This research is part of Elena Arboleya García thesis from PhD Programme in Education and Psychology. Laura Miralles holds a Torres Quevedo grant from the Government of Spain (PTQ2018-010019).

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

References

1. Huizinga, J. *Homo Ludens*, 6th ed.; Alianza Editorial: Madrid, Spain, 2007.
2. Caillois, R. *Man, Play and Games*; University of Illinois Press: Champaign, IL, USA, 2001.
3. Allery, L.A. Educational games and structured experiences. *Med. Teach.* **2004**, *26*, 504–505. [CrossRef]
4. Backlund, P.; Hendrix, M. Educational games-are they worth the effort? A literature survey of the effectiveness of serious games. In Proceedings of the 2013 5th International Conference on Games and Virtual Worlds for Serious Applications (VS-GAMES), Poole, UK, 11–13 September 2013.
5. Connolly, T.M.; Boyle, E.A.; MacArthur, E.; Hainey, T.; Boyle, J.M. A systematic literature review of empirical evidence on computer games and serious games. *Comput. Educ.* **2012**, *59*, 661–686. [CrossRef]
6. Qian, M.; Clark, K.R. Game-based Learning and 21st century skills: A review of recent research. *Comput. Hum. Behav.* **2016**, *63*, 50–58. [CrossRef]
7. Abt, C.C. *Serious Games*; University Press of America: Lanham, MD, USA, 1987.
8. Al-Azawi, R.; Al-Faliti, F.; Al-Blushi, M. Educational gamification vs. Game based learning: Comparative study. *Int. J. Innov. Manag. Technol.* **2016**, *7*, 132–136. [CrossRef]
9. Djaouti, D.; Álvarez, J.; Jessel, J.P. Classifying serious games: The G/P/S model. In *Handbook of Research on Improving Learning and Motivation through Educational Games: Multidisciplinary Approaches*; Felicia, P., Ed.; IGI Global: Hershey, Pennsylvania, USA, 2011; pp. 118–136. [CrossRef]
10. Aranda Juárez, D.; Gómez García, S.; Navarro Remesal, V.; Planells de la Maza, A.J. *Game & Play: Diseño y Análisis del Juego, el Jugador y el Sistema Lúdico*; UOC Press-Comunication: Barcelona, Spain, 2015.
11. Khan, A.; Pearce, G. A study into the effects of a board game on flow in undergraduate business students. *Int. J. Manag. Educ.* **2015**, *13*, 193–201. [CrossRef]
12. Anneta, L.A. The "I's" have it: A framework for serious educational game design. *Rev. Gen. Psychol.* **2010**, *14*, 105–112. [CrossRef]
13. Subhash, S.; Cudney, E.A. Gamified learning in higher education: A systemic review of the literature. *Comput. Hum. Behav.* **2018**, *87*, 192–206. [CrossRef]
14. De Freitas, S. *Learning in Immersive Worlds: A Review of Game-Gased Learnging*; Published Version Deposited in CURVE September 2013 Original; Joint Information Systems Committee: Bristol, UK, 2013.
15. Cheng, P.H.; Yeh, T.K.; Chao, Y.K.; Lin, J.; Chang, C.Y. Design ideas for an issue-situation-based board game involving multirole scenarios. *Sustainability* **2020**, *12*, 2139. [CrossRef]
16. Piñero Charlo, J.C. Análisis sistemático del uso de salas de escape educativas: Estado del arte y perspectivas de future. *Espacios* **2019**, *40*, 9.
17. Bai, S.; Foon, K.; Huang, B. Does gamification improve student learning outcome? Evidence from a meta-analysis and synthesis of qualitative data in educational contexts. *Educ. Res. Rev.* **2020**, *30*, 100322. [CrossRef]
18. Cardinot, A.; Fairfield, J.A. Game-based learning to engage students with physics and astronomy using a board game. *IJGBL* **2019**, *9*, 42–57. [CrossRef]
19. Talan, T.; Doğan, Y.; Batdı, V. Efficiency of digital and non-digital educational games: A comparative meta-analysis and a metathematic analysis. *J. Res. Technol. Educ.* **2020**, *52*, 474–514. [CrossRef]
20. Franklin, S.; Peat, M.; Lewis, A. Non-traditional interventions to stimulate discussion: The use of games and puzzles. *J. Biol. Educ.* **2003**, *37*, 79–84. [CrossRef]
21. Boghian, I.; Cojocariu, V.M.; Popescu, C.V.; Mâţă, L. Gambe-based learning. Using board games in adult education. *J. Educ. Sci. Psychol.* **2019**, *9*, 51–57.

22. Hakak, S.; Noor, N.F.M.; Ayub, M.N.; Affal, H.; Hussin, N.; Ahmed, E.; Imran, M. Cloud-assisted gamification for education and learning-Recent advances and challenges. *Comput. Electr. Eng.* **2019**, *74*, 22–34. [CrossRef]
23. Lester, J.C.; Spires, H.A.; Nietfeld, J.L.; Minogue, J.; Mott, B.W.; Lobene, E.V. Designing game-based learning environments for elementary science education: A narrative-centered learning perspective. *Inf. Sci.* **2014**, *264*, 4–18. [CrossRef]
24. Antunes, M.; Pacheco, M.A.R.; Giovanela, M. Design and implementation of an educational game for teaching chemistry in higher education. *J. Chem. Educ.* **2012**, *89*, 517–521. [CrossRef]
25. García-Molina, R. Ciencia recreativa: Un recurso didáctico para enseñar deleitando. *Rev. Eureka Sobre Enseñanza Y Divulg. De Las Cienc.* **2011**, *8*, 370–392. [CrossRef]
26. Sardone, N.B.; Devlin-Scherer, R. Let (board) games begin: Creative ways to enhance teaching and learning. *Clear. House* **2016**, *89*, 215–222. [CrossRef]
27. Kober, S.E.; Wood, G.; Kiili, K.; Moeller, K.; Ninaus, M. Game-based learning environments affect frontal brain activity. *PLoS ONE* **2020**, *15*, e0242573. [CrossRef]
28. Avdiu, E. Game-Based Learning Practices in Austrian Elementary Schools. *Educ. Process Int. J.* **2019**, *8*, 196–206. [CrossRef]
29. Higueras-Rodríguez, L.; Medina-García, M.; Molina-Ruiz, E. Analysis of courses and teacher training programs on playful methodology in Andalusia (Spain). *Educ. Sci.* **2020**, *10*, 105. [CrossRef]
30. Lickiewicz, J.; Paulsen Hughes, P.; Makara-Studzińska, M. The use of board games in healthcare teaching. *Nurs. Probl.* **2020**, *28*, 71–74. [CrossRef]
31. Taspinar, B.; Schmidt, W.; Schuhbauer, H. Gamification in education: A board game approach to knowledge acquisition. *Procedia Comput. Sci.* **2016**, *99*, 101–116. [CrossRef]
32. D'Astous, A.; Gagnon, K. An inquiry into the factors that impact on consumer appreciation of a board game. *J. Consum. Mark.* **2007**, *24*, 80–89. [CrossRef]
33. Liomas, I.; Altanis, I.; Retails, S. An authoring toolkit for creating digital learning board games for cognitive and social skills development. In Proceedings of the 2017 IEEE Global Engineering Education Conference (EDUCON), Athens, Greece, 25–28 April 2017; pp. 508–513.
34. Chiarello, F.; Castellano, M.G. Board games and board game design as learning tool for complex scientific concepts: Some experiences. *IJGBL* **2016**, *6*, 1–14. [CrossRef]
35. Tsai, J.C.; Cheng, P.H.; Liu, S.Y.; Chang, C.Y. Using board games to teach socioscientific issues on biological conservation and economic development in Taiwan. J. *Baltic Sci. Educ.* **2019**, *18*, 634–645. [CrossRef]
36. Tasmin, R.; Yahya, S. "Old fashioned, yet admirable". Revisiting Bloom to revolutionize board gaming in our entrepreneurship classrooms. *ACRN J. Entrep. Perspect.* **2014**, *3*, 31–42.
37. Bayeck, R.Y. Examining board gameplay and learning: A multidisciplinary review of recent research. *Simul. Gaming* **2020**, *51*, 411–431. [CrossRef]
38. William, L.; Rahim, Z.A.B.A.; De Souza, R.; Nugroho, E.; Fredericco, R. Extendable board game to facilitate learning in supply chain management. *ASTESJ* **2018**, *3*, 99–111. [CrossRef]
39. Siwela, M. Making serious learning easy and fun at OHFT: Educational board games. *Libr. Inf. Res.* **2020**, *43*. [CrossRef]
40. Matera, M. *Explora Como un Pirata*; Mensajero: Bilbao, Spain, 2018.
41. Gonzalo-Iglesia, J.L.; Lozano-Monterrubio, N.; Prades-Tena, J. Noneducational board games in University Education. Perceptions of students experiencing game-based learning methodologies. *Rev. Lusófona De Educ.* **2018**, *41*, 45–62. [CrossRef]
42. Miralles, L.; Morán, P.; Dopico, E.; García-Vázquez, E. DNA Re-EvolutioN: A game for teaching learning molecular genetics and evolution. *Biochem. Mol. Biol. Educ.* **2013**, *41*, 396–401. [CrossRef]
43. Parrondo, M.; Rayón-Viña, F.; Borrel, Y.J.; Miralles, L. Sustainable Sea: A board game for engaging students in sustainable fisheries management. *Appl. Environ. Educ. Commun.* **2021**, *20*, 406–421. [CrossRef]
44. Muell, M.R.; Guillory, W.X.; Kellerman, A.; Rubio, A.O.; Scott-Elliston, A.; Morales, O.; Eckhoff, K.; Barfknecht, D.; Hartsock, J.A.; Weber, J.J. Gaming natural selection: Using board games as simulations to teach evolution. *Evolution* **2020**, *74*, 681–685. [CrossRef]
45. Juan, Y.K.; Chao, T.W. Game-based learning for green building education. *Sustainability* **2015**, *7*, 5592–5608. [CrossRef]
46. Tanel, R.; Önder, E.B. Developing and testing a board game to learn about stars. *IJGBL* **2020**, *10*, 62–73. [CrossRef]
47. Queiroz de Cavalho, J.C.; Beltramini, L.M.; Segnini Bossolan, N.R. Using a board game to teach protein synthesis to high school students. *J. Biol. Educ.* **2018**, *53*, 205–216. [CrossRef]
48. West, S. A bird-based game takes wing. *Nature* **2019**, *569*, 334–335. [CrossRef]
49. Steinberger, F.; Minder, T.; Trutnevyte, E. Efficiency versus Equity in Spatial Siting of Electricity Generation: Citizen Preferences in a Serious Board Game in Switzerland. *Energies* **2020**, *13*, 4961. [CrossRef]
50. Cheng, P.H.; Yeh, T.K.; Chao, Y.K.; Lin, J.; Chang, C.Y. Development of an issue-situation-based board game: A systematic learning evironment for wáter resourde adpatation education. *Sustainability* **2019**, *11*, 1341. [CrossRef]
51. Grechus, M.; Brown, J. Comparison of individualized computer game reinforcement versus peer-interactive board game reinforcement on retention of nutrition label knowledge. *J. Health Educ.* **2000**, *31*, 138–142. [CrossRef]
52. Argenton, L.; Muzio, M.; Shek, E.J.; Mantovani, F. Multiplayer serious games and user experience: A comparison between paper-based and digital gaming experience. In *Games and Learning Alliance. GALA 2014. Lecture Notes in Computer Science*; De Gloria, A., Ed.; Springer: Cham, Switzerland, 2014; pp. 54–62. [CrossRef]

53. Martindale, R.C.; Weiss, A.M. Taphonomy: Dead and fossilized: A new board game designed to teach college undergraduate students about the process of fossilization. *J. Geosci. Educ.* **2020**, *68*, 265–285. [CrossRef]
54. Rose, T.M. A board game to assist Pharmacy students in learning metabolic pathways. *Am. J. Pharm. Educ.* **2011**, *75*, 183. [CrossRef] [PubMed]
55. Martín-Lara, M.A.; Calero, M. Playing a board game to learn bioenergy and biofuels topics in an interactive, engaging context. *J. Chem. Educ.* **2020**, *97*, 1375–1380. [CrossRef]
56. Calvo, L.F.; Herrero Martínez, R.; Paniagua Bermejo, S. Influencia de procesos de ludificación en entornos de aprendizaje STEM para alumnos de Educación Superior. *Trilogía Cienc. Tecnol. Soc.* **2020**, *12*, 35–68. [CrossRef]
57. Ocean Literacy: The Essential Principles and Fundamental Concepts of Ocean Sciences for Learners of All Ages (2020). Available online: https://oceanliteracy.unesco.org/resource/ocean-literacy-the-essential-principles-and-fundamental-concepts-of-ocean-sciences-for-learners-of-all-ages-2020/ (accessed on 1 September 2021).
58. Fjællingsdal, K.S.; Klöckner, C.A. Green across the board: Board games as tools for dialogue and simplified environmental communication. *Simul. Gaming* **2020**, *51*, 632–652. [CrossRef]
59. Cudaback, C. Ocean literacy. There's more to it than content. *Oceanography* **2008**, *21*, 10–11. [CrossRef]
60. MacNeil, S.; Hoover, C.; Ostertag, J.; Yumagulova, L.; Glithero, L. Coming to termes with ocean literacy. *Can. J. Environ. Educ.* **2021**, *24*, 233–252.
61. West, D. Ocean literacy is key to preserving our oceans and coasts. *Mar. Technol. Soc. J.* **2004**, *38*, 68–69. [CrossRef]
62. Veronica, R.; Calvano, G. Promoting Sustainable Behavior Using Serious Games: SeAdventure for Ocean Literacy. *IEEE Access* **2020**, *8*, 196931–196939. [CrossRef]
63. Worm, B.; Elliff, C.; Fonseca, G.J.; Gell, F.R.; Serra-Gonçalves, C.; Helder, N.K.; Murray, K.; Peckham, H.; Prelovec, L.; Sink, K. Making ocean literacy inclusive and accessible. *Ethics Sci. Environ. Politics* **2021**, *21*, 1–9. [CrossRef]
64. Caro Saiz, J.; Díaz-de la Fuente, S.; Ahedo, V.; Zurro Hernández, D.; Madella, M.; Galán, J.M.; Izquierdo, L.R.; Santos, J.I.; del Olmo, R. *Terra Incógnita: Libro Blanco Sobre Transdisciplinariedad y Nuevas Formas de Investigación en el Sistema Español de Ciencia y Tecnolog*; PressBooks: Madrid, Spain, 2020.
65. Giménez Pardo, C.; Pagés Arévalo, C.; Martínez Herráiz, J.J. Análisis, diseño y desarrollo de un juego educativo para ordenador sobre enfermedades tropicales y salud internacional: Una herramienta docente más de apoyo al profesor. *Rev. De Docencia Univ.* **2011**, *8*, 131–146. [CrossRef]
66. Domínguez, A.; Saenz-de-Navarrete, J.; de-Marcos, L.; Fernández-Sanz, L.; Pagés, C.; Martínez-Herráiz, J.J. Gamifying learning experiences: Practical implications and outcomes. *Comput. Educ.* **2013**, *63*, 380–392. [CrossRef]
67. Huizenga, J.C.; Ten Dam, G.T.M.; Voogt, J.M.; Admiraal, W.F. Teacher perceptions of the value of game-based learning in secondary education. *Comput. Educ.* **2017**, *110*, 105–115. [CrossRef]
68. Bopp, M. Didactic analysis of digital games and game-based learning. In *Affective and Emotional Aspects of Human-Computer Interaction*, 2nd ed.; Pivec, M., Ed.; IOS Press: Amsterdam, The Netherlands, 2006; Volume 1, pp. 8–37.
69. Hassan, M.M.; Abdullah-Al-Wadud, M.; Almogren, A.; Rahman, S.M.M.; Alelaiwi, A.; Alamri, A.; Hamid, M.A. QoS and trust-aware coalition formation game in data-intensive cloud federations. *Concurr. Comput. Pract. Exp.* **2016**, *28*, 2889–2905. [CrossRef]
70. McMillan, J.H.; Schumacher, S. *Investigación Educativa*, 5th ed.; Pearson Educación: Madrid, Spain, 2005.
71. León, O.G.; Montero, I. *Diseño de Investigaciones*, 2nd ed.; McGraw Hill: Madrid, Spain, 1997.
72. Rodríguez Gómez, G.; Gil Flores, J.; García Jiménez, E. *Metodología de la Investigación Cualitativa*; Ediciones Aljive: Málaga, Spain, 1996.
73. Guzmán, P. *Estadística Elemental Aplicada a la Educación*; Editorial Escuela Española: Madrid, Spain, 1960.
74. Welkowitz, J.; Ewen, R.B.; Cohen, J. *Estadística Aplicada a las Ciencias de la Educación*; Aula XXI/Santillana: Madrid, Spain, 1986.
75. Rodríguez Ruiz, O. La Triangulación Como Estrategia de Investigación en Ciencias Sociales. *Rev. Madr.* **2005**, *31*, 2–4.
76. Klöckner, C.A. *The Psychology of Pro-Environmental Communication: Beyond Standard Information Strategies*, 1st ed.; Palgrave Macmillan: London, UK, 2015.
77. Rebolledo-Mendez, G.; Avramides, K.; De Freitas, S.; Memarzia, K. Societal impact of a serious game on raising public awareness: The case of FloodSim. In Proceedings of the 2009 ACM SIGGRAPH Symposium on Video Games, New Orleans, LA, USA, 4–6 August 2009; pp. 15–22.
78. Buckley, P.; Doyle, E. Gamification and student motivation. *Interact. Learn. Environ.* **2016**, *24*, 1162–1175. [CrossRef]
79. Holzmann, S.L.; Schäfer, H.; Groh, G.; Plecher, D.A.; Klinder, G.; Schauberger, G.; Hauner, H.; Holzpfel, C. Short-term effects of the serious game "Fit, food, fun" on nutritional knowledge: A pilot study among children and adolescents. *Nutrients* **2019**, *11*, 2031. [CrossRef]
80. Rodríguez Barreiro, L.M.; Escudero Escorza, T. Interacción entre iguales y aprendizaje de conceptos científicos. *Enseñanza De Las Cienc.* **2000**, *18*, 255–274. [CrossRef]
81. Meza Arcos, L.; García Vigil, H. El juego como un elemento favorecedor al acercamiento de las ciencias: En particular, en las actividades deficiencia recreativa. In *X Reunión de la Red de Popularización de la Ciencia y la Tecnología en América Latina y el Caribe (RED POP-UNESCO) y IV Taller Ciencia*; Comunicación y Sociedad: San José, Costa Rica, 2007.
82. McCauley, D.J.; Pinsky, M.L.; Palumbi, S.R.; Estes, J.A.; Joyce, F.H.; Warner, R.R. Marine defaunation: Animal loss in the global ocean. *Science* **2015**, *347*, 1255641. [CrossRef] [PubMed]

83. Jefferson, R.; McKinley, E.; Capstick, S.; Fletcher, S.; Griffin, H.; Milanese, M. Understanding audiences: Making public perceptions research matter to marine conservation. *Ocean. Coast. Manag.* **2015**, *115*, 61–70. [CrossRef]
84. Rodela, R.; Ligtenberg, A.; Bosma, R. Conceptualizing Serious Games as a Learning-Based Intervention in the Context of Natural Resources and Environmental Governance. *Water* **2019**, *11*, 245. [CrossRef]

education sciences

Article

Similarities in Procedures Used to Solve Mathematical Problems and Video Games

Juan Antonio Antequera-Barroso [1,*], Francisco-Ignacio Revuelta-Domínguez [2] and Jorge Guerra Antequera [2]

[1] Department of Didactics of Experimental Sciences and Mathematics, Teacher Training College, University of Extremadura, 10071 Cáceres, Spain
[2] Department of Educational Sciences, Teacher Training College, University of Extremadura, 10071 Cáceres, Spain; fird@unex.es (F.-I.R.-D.); guerra@unex.es (J.G.A.)
* Correspondence: jaab@unex.es

Abstract: Video game use is widespread among all age groups, from young children to older adults. The wide variety of video game genres, which are adapted to all tastes and needs, is one of the factors that makes them so attractive. In many cases, video games function as an outlet for stress associated with everyday life by providing an escape from reality. We took advantage of this recreational aspect of video games when investigating whether there are similarities between the procedures used to pass a video game level and those used to solve a mathematical problem. Moreover, we also questioned whether the use of video games can reduce the negative emotions generated by mathematical problems and logical–mathematical knowledge in general. To verify this, we used the Portal 2 video game as a research method or tool. This video game features concepts from the spatial–geometric field that the students must identify and relate in order to carry out the procedures required to solve challenges in each level. The procedures were recorded in a questionnaire that was separated into two blocks of content in order to compare them with the procedures used to solve mathematical problems. The first block pertains to the procedures employed and the second block to the emotions that the students experienced when playing the video game and when solving a mathematical problem. The results reveal that the recreational aspect of video games is more important than the educational aspect. However, the students were not aware of using the problem-solving procedures they learned at school to solve different challenges in the video games. Furthermore, overcoming video game challenges stimulates positive emotions as opposed to the negative emotions generated when solving mathematical problems.

Keywords: mathematical problem-solving; video games; emotions; Portal 2

Citation: Antequera-Barroso, J.A.; Revuelta-Domínguez, F.-I.; Guerra Antequera, J. Similarities in Procedures Used to Solve Mathematical Problems and Video Games. *Educ. Sci.* **2022**, *12*, 172. https://doi.org/10.3390/educsci12030172

Academic Editor: José Carlos Piñero Charlo

Received: 27 December 2021
Accepted: 26 February 2022
Published: 1 March 2022

1. Introduction

Current technological developments emerge in all social, cultural, and educational contexts. Among these developments, digital whiteboards or didactic software are examples of applications and hardware designed for the educational context. However, there are also digital elements that, despite not being designed for the teaching–learning process, have been used for this purpose. In light of this, video games could be considered based on the same essence as traditional games. McGonigal [1] states that a video game must be based on the premise of overcoming a challenge and being motivated to do so. Therefore, when interacting with these recreational applications, the individual must: (a) analyse the challenge that appears before them and determine what its purpose is; (b) analyse which elements in the game represent support (power-ups) or which elements are negative (enemies, traps, or penalties); (c) discover how to progress or gain experience; (d) consider action sequences by trial-and-error exercises; and (e) put decision-making skills into practice [2]. A careful analysis of the previously mentioned skills reveals that they are similar to those used in problem-solving.

Based on this, problem-solving is one of the most relevant areas in logical–mathematical knowledge. In fact, problem-solving can be applied to the field of mathematics as well as to aspects of daily life: when people encounter situations that require a solution in their daily lives, they unconsciously apply the problem-solving method they learned in school. In this manner, mathematical competence is developed through problem-solving exercises. According to Gorgorió and Albarracín [3]:

> *Mathematical competence is the ability to use mathematical knowledge in a cross-cutting manner in mathematical and non-mathematical situations and contexts. Mathematical competence goes beyond procedural knowledge; it is manifested in the use of conceptual knowledge in different practical situations.*
>
> (pp. 116–117)

In view of this definition of mathematical competence, it could be stated that video games are included in these non-mathematical contexts. However, the question would be whether video games can be used in mathematical contexts, such as classrooms, during mathematics or science classes. According to the literature on this topic, the answer is yes. Various studies describe the use of these elements in the classroom—for example, using the Angry Birds video game to develop mathematical knowledge [4–6] or physical knowledge [7–11].

1.1. Problem-Solving

Problem-solving could be considered one of the most important curricular activities in all the stages of a country's educational system. Analysing the current legislation, one can see that, in all cases, problem-solving is oriented towards problems in children's daily lives. Focusing on Spain (whose legislation stipulates that problem-solving be present from the earliest stages of education), self-confidence, the capacity for initiative, and problem-solving are developed from early childhood education onwards [12]. In primary education, problem-solving competencies are also developed within the field of mathematics, together with others, such as reading, reflection, planning processes, establishing resolution strategies, and designing and evaluating procedures [13]. In both stages, problem-solving is based on the development of different skills that allow students to address the situation and/or problem while developing skills related to personal development, personal autonomy, confidence, and motivation to overcome situations in their daily lives.

The logical–mathematical skills to be developed are established sequentially through a series of phases. As a result of these phases, a methodology for solving mathematical problems that is applicable to any situation is established. One of the most well-described and frequently used methodologies is that of Polya [14], which outlines four phases to pose and solve a problem through a series of questions set out in a method (Table 1).

Table 1. Polya's problem-solving phases.

Phases	Questions
Understanding the problem	What is the unknown? What data do I have? What is the condition? Is it enough to find the unknown? Is it redundant, contradictory, or insufficient?
Devising a plan	Have I seen this problem before? Do I know of any similar problems?
Carrying out the plan	Am I sure that each step is correct? Can I prove that the step is correct?
Looking back	Can I check the result and the reasoning? Can I derive the solution differently?

Source: own elaboration based on Polya [14].

Mason, Burton, and Stacey [15] described another method of phased problem-solving, which is divided into three phases—entry, attack, and review. As with the previous method, in each of its phases, a series of questions are posed that allow the individual to progress (Table 2).

Table 2. Summary of Mason, Burton, and Stacey's problem-solving phases.

<table>
<tr><th>Phases</th><th>Processes</th><th>Issues or Propositions</th><th>States</th></tr>
<tr><td>Entry</td><td rowspan="2">Specialising</td><td>What do I KNOW?
What do I WANT?
What can I INTRODUCE?</td><td rowspan="2">STUCK!</td></tr>
<tr><td rowspan="2">Attack</td><td>CONJECTURE</td></tr>
<tr><td rowspan="2">Generalising</td><td>Try (Attempt)
Check and distrust (Maybe)
But why?</td><td rowspan="2">AHA!</td></tr>
<tr><td>Review</td><td>CHECK the resolution
REFLECT on the key ideas and key moments
GENERALISE to a wider context</td></tr>
</table>

Source: own elaboration based on Mason et al. [15].

Within the description of the method presented by Mason et al. [15], as well as the phases, there are processes such as specialising—typical of the entry and attack phases—and generalising—typical of the attack and review phases. The method introduces the concepts of STUCK! and AHA!—concepts related to the manner of dealing with problem-solving and the learning possibilities that can be extracted from solving the problem.

Being in the STUCK! phase leads to many cases of frustration and a lack of motivation to move forward. Recent studies [16] introduce a new phase in problem-solving methods, in which the identification and control of emotions that arise when solving a problem play an important role. Di Leo et al. [17] indicate that the main emotions that students experience when solving a mathematical problem are frustration and confusion, which are negative emotions. Managing negative emotions, such as confusion, can lead to positive emotions that help with solving the problem. According to Caballero, Blanco, and Guerrero [18], it is necessary to introduce emotional aspects as well as cognitive aspects in mathematical problem-solving. By doing so, we can develop techniques, such as relaxation or breathing techniques, that allow us to transform negative emotions, such as anxiety, into positive emotions. Hannin and Nieuwenhoven [19] found a reduction in negative emotions in students who had developed cognitive and emotional aspects versus those who had only received training in problem-solving, although the cognitive levels were equivalent. Therefore, it is necessary to take into account cognitive and emotional changes as a whole, rather than individually, to understand students' performance when solving mathematical problems [20]. These changes move students from the STUCK! phase to the AHA! phase.

1.2. Video Games for Problem-Solving

A series of logical–mathematical skills are employed when solving a mathematical problem. These skills can be used to overcome the challenges posed by the different phases of a video game, thus providing a number of opportunities to put mathematical knowledge into practice [21]. Among these skills are observing the elements of the screen or level, differentiating useful elements or accessories, designing strategies, and anticipating results from the objects [22–24]. Visuospatial and spatial–geographical skills are also required to interpret plans or areas of the screen. As such, video games provide an opportunity to develop mathematical logic and to establish processes of observation, relation, and operation or transformation.

1.3. Research Questions and Objectives

Considering the relationship that exists between the use of video games and logical–mathematical knowledge, we have posed the following research questions and their corresponding objectives.

Research Question 1. Are the procedures that students use to pass a level in a video game and to solve a mathematical problem comparable?

Objective 1. To verify if the mathematical problem-solving procedures used by students are similar to those they use to pass a level of a video game.

Research Question 2. Do students experience similar feelings when passing a level in a video game and solving a mathematical problem?

Objective 2. To compare the feelings that students experience while playing a video game with those they experience when solving a mathematical problem.

Based on the previous paragraphs, the aim of this study is to discover whether the procedures used to complete video game levels are similar to those used in problem-solving, and to compare whether there are any similarities between the main characteristics of a video game and the characteristics of a mathematical problem. Furthermore, we also aim to observe the emotions students experience when playing video games and compare them with the emotions they experience when solving a mathematical problem.

2. Materials and Methods

2.1. Population and Sample

This study was carried out at the University of Cadiz, in the Faculty of Education Sciences. The participants were 170 trainee teachers taking the subject "Mathematical Knowledge in Early Childhood Education" of the bachelor's degree in early childhood education (n = 170). We chose to select students taking this subject because it involves developing the first of the three pillars that constitute didactics—that is, logical–mathematical knowledge, in which they develop their own discourse on the construction of this knowledge.

2.2. Method

In order to answer the research questions posed, we decided to use a video game that we know as a research method or tool. We chose the Portal 2 video game, developed by the Valve Corporation, to work on problem-solving with our students. We chose this video game because we were aware of its potential to impart logical–mathematical and spatial–geometric knowledge, which allows students to improve visuospatial competence, and, therefore, to identify shapes or objects that appear in the scene. By looking for the relationship between the shapes and objects that appear on the screen, students obtain information and develop a strategy to pass the level. Portal 2 is a platform/action game with puzzles that appear in the form of a series of riddles on the walls and objects to solve in order to pass to the next level. Hence, we considered it an interesting option to compare the students' perception of both the video game and solving a mathematical problem, in accordance with Shute et al. [25,26] and Avry et al. [27].

Chorianopoulos and Giannakos [28] highlight the existence of four basic principles in video games that relate them to mathematical knowledge. The following table (Table 3) shows the principles and their relationship with the chosen video game, Portal 2, and mathematical problem-solving.

Table 3. Relationship between the basic principles of video games and problem-solving.

Principles	Video Game	Problem-Solving
1st. Hero or heroine. Their story	The video game's main character is trapped in a futuristic laboratory, controlled by an artificial intelligence called GLaDOS, from which she must escape to save her life.	Statement. Understand the problem, the objectives, and the challenges posed.
2nd. Use of known techniques in the video game	The main character must identify the elements that appear on the screen that can help her pass the level. In order to do so, she can use a portal gun to move objects and open portals in search of items that will allow her to accomplish the mission.	Find known mathematical procedures from the data provided by the statement.
3rd. Involve people in the trial-and-error method.	The completion of different tests forces the main character to open portals in different walls that make up the room to find the evidence.	Find the most appropriate solution to the problem, facilitating its resolution.
4th. Collaborative learning	The video game provides a multiplayer option, with which collaborative learning is developed to pass the different logic games posed.	Analysis and critical-reflective debate that lead to the peers solving the problem amongst themselves.

Source: own elaboration based on the principles of Ref. [28].

Once the video game had been selected, the students were given a brief presentation on the video game, its context, how to install it, its controls, and the instructions in order to carry out the task correctly. Then, the class was divided into groups of four or five students, and the furniture was rearranged so that the students could work collaboratively. This facilitated both the development of the activity individually and, at a later stage, the sharing of findings and the discussion of relevant questions or doubts that the students had encountered during the activity. This configuration was chosen because group work favours dialogue, critical reflection, and sharing ideas through negotiation. It also allows the teacher to intervene as a dialogue guide or advisor, sharing reflections or doubts with the students and enriching the activity and its result.

The implementation of the task was divided into three parts. The first part consisted of a period of individual free play so that the students could set up the controls to their liking and get used to the dynamics of the game in the first levels, which had a tutorial function. Once the students understood the dynamics of the game, the second part of the task focused on passing the different levels by looking for the procedures required to solve them. At this part, a dialogue was established on various occasions between the students as doubts arose about how to solve the puzzles, the clues, or the handling of the main character. The third part was carried out as a way of closing the activity. At this stage, the students completed a questionnaire that was divided into different blocks. In the first block, descriptive data were collected, such as sex, age, previous studies, if they were a video game player, and the number of hours they spent playing video games. In the second block, they were asked to describe the procedure they followed to pass the different levels. They were asked to describe, step by step, what they had done, what they had looked at, and what decisions they had made in order to solve the problem. In another session, the answers given were analysed and compared with the problem-solving models of Polya and Mason et al., providing an opportunity for the students to analyse and reflect on their findings as a group. Finally, in the last block, they had to express their impressions, feelings, or emotions regarding working with logical–mathematical knowledge in this way. In order to do so, they used a Likert scale and recorded their degree of agreement or disagreement with the statements shown. The statements used in the questionnaire were written according to both the opinions expressed by the students and the objectives set out in this task. The students were also asked to include a brief comment justifying their answer to each of the statements in the questionnaire. Table 4, with the distribution of the work during the various sessions conducted, is presented below.

Table 4. Timetable of sessions.

Session	Activity	Duration (Minutes)
Session 0	1. Presentation of the activity	15
	2. Video game installation	20
	3. Video game configuration	5
	4. Free play	30
	5. Sharing of views	20
Session 1	1. Introduction to the session	5
	2. Free play	25
	3. Discussion and analysis of the video game	25
	4. Blocks I and II of the questionnaire	25
Session 2	1. Introduction to the session	5
	2. Presentation of the two problem-solving models	15
	3. Discussion and analysis of the answers given in Block II of Session 1 in terms of the two models	30
	4. Block III of the questionnaire	25
	5. Finishing the activity	5

Source: own elaboration.

2.3. Instruments

The instrument used was a questionnaire prepared for the study with blocks relating to descriptive data, video game consumption and typology, general knowledge about video games, questions about the activity carried out, and the didactic possibilities of Portal 2 (Figure 1).

Figure 1. Screenshot of the questionnaire (bit.ly/2Z08sbd). (Late date of access: 28 January 2022).

Questionnaire: Teach with Portals: This questionnaire has been designed for the students of the bachelor's degree in early childhood education at the University of Cadiz in order to analyse their experience of using logical –mathematical knowledge when playing the Portal 2 video game.

2.4. Data Analysis

Data collection was carried out following a mixed methodology approach—both quantitative and qualitative—in order to observe the data and thus gain a better understanding of the usefulness of the activity from different perspectives, as indicated by Creswell [29] (p. 18). Qualitative aspects were employed when analysing the problem-solving phases used by the students to pass the levels and comparing them with those indicated by Polya [14] and Mason, Burton, and Stacey [15]. Quantitative aspects were employed when analysing the students' emotions or feelings towards this logical–mathematical knowledge.

Employing both analyses allowed us to provide more in-depth answers to the research questions posed and to fulfil the objectives of this study. Furthermore, to show the validity or internal consistency of our analysis, we carried out a study of the correlations between the different answers our students gave to the statements shown in the third block of the questionnaire. In order to do so, the statistical software Jamovi v.1.8.4 was used.

3. Results and Discussion

The distribution of students by sex shows that the majority of our students were women, 95%, and the rest were men. In terms of their ages, they were between 19 and 24 years old, although there was one 50-year-old student (Table 5).

Table 5. Distribution of the students in the 2nd year of the bachelor's degree in early childhood education by sex.

	Frequency	Percentage (%)
Female	161	95
Male	9	5
Total	170	100

Source: own elaboration.

One of the questions the students responded to in the questionnaire was related to what Novak and Tassell [30]—citing Stevens and Bavelier (2012)—indicate regarding whether video game players of action games exhibit greater memory, spatial, and geometric skills than non-video game players. These players focus their attention on relevant facts or data and ignore irrelevant information, which is a characteristic that is important when solving mathematical problems. Novak and Tassell [30] also indicate that players improve this characteristic after several hours of gameplay regardless of whether or not the game is an action one. In the case of this study, 46 individuals considered themselves to be video game players. The rest either did not define themselves or did not consider themselves to be video game players because they did not have an established playing routine (Table 6).

Table 6. Distribution of the students in the 2nd year of the bachelor's degree in early childhood education according to whether or not they consider themselves to be video game players.

	Female		Male	
	Frequency	Percentage (%)	Frequency	Percentage (%)
Yes	41	26	5	56
No	114	71	4	44
DK/NR	6	3	0	0
Total	161	100	9	100

Source: own elaboration.

In light of this response, one might think that students have the logical–mathematical skills to solve the challenges or problems posed, as Novak and Tassell [30] commented. In the second block of the questionnaire, the students had to reflect on the procedures they followed to pass different levels of the Portal 2 video game. Considering the procedures described by the students, we were able to distinguish or codify three types of players. The first type of player (J1) passes the levels without difficulty, with (J11) or without (J12) requiring external help. The second type of player (J2) is stuck because of not being able to find the clues. This type of player is further divided into two types—those who managed to continue the game despite being stuck (J21) and those who required some kind of help to continue playing (J22). Finally, there are those players who declined to continue playing regardless of whether they refused to continue without help (J31) or with help (J32).

Below are the answers given by our students, Tables 7–12, analysed from the point of view of the two problem-solving models.

Table 7. Procedures followed by students to pass the level following Polya's model (1989).

Phase	Explanation
Understanding the problem	"I must leave this level. The objective is to open the exit door. I have to look for the clues on the screen and match them. The clues can be in this room or in the rooms next door."
Devising a plan	"The clues tell me that I must first perform an action to get to the push button to open the door. I will follow the clues to see what I have to do."
Carrying out a plan	"I will open the necessary portals to follow the clues. If some portals do not work for me, I can always go back. I have to be careful, as some portals can confuse me when I see the main character moving. In addition, I will move objects that may be in the way or that need to be moved to open the level's exit door."
Looking back	"I have managed to open this level's exit door. I can pass it, but I have opened more portals than necessary. My peers have passed before me with fewer moves. I have learned techniques to move around the level."

Source: own elaboration.

Table 8. Procedures followed by students to pass the level following the model of Mason et al. (1992).

Phase	Explanation
Entry	"I know I have to exit the level through the door that appears and is locked. In order to do this, I have to look at the clues on the walls and objects on the screen. To do this, I can use the portal gun to search for clues or objects that are in other rooms of the level."
Attack	"When I see the clues, I have to relate them to the actions I have to perform. I will open the necessary portals and move objects to block push buttons. If my decisions are right, I will get close to the exit door, and I will be able to open it. I must check the portals, so I do not get lost in the game."
Review	"I have passed the level. I was able to match the clues that appeared in the level. I have seen actions that will help me for the following levels."

Source: own elaboration.

Table 9. Procedures followed by students to pass the level following Polya's model (1989).

Phase	Explanation
Understanding the problem	"I have to open the door that appears on the screen to pass to the next level. There are enough clues in the level to pass. I must follow them."
Devising a plan	"I must follow the clues and match them. I have to go through the necessary walls or move objects with the portal gun in order to solve the puzzles."
Carrying out a plan	"I recognised the clues and tried to follow them. I opened portals, but I got lost in them and did not know how to get out. I saw a character running and tried to follow her, thinking it was a clue. I ended up getting disoriented. I had to stop and look at the clues again and realised that the character I was chasing was myself."
Looking back	"I know I need to find the best place to open the portals so that they do not become more of a problem in the end. I need to look carefully at the clues and think them through before opening a portal or moving an object".

Source: own elaboration.

Table 10. Procedures followed by students to pass the level following the model of Mason et al. (1992).

Phase	Explanation
Entry	"The objective is to open the exit door to pass the level. I have to look at the clues that appear and match them. The portals will help me find objects and new clues."
Attack	"I had to follow clues and open portals. In some cases, the portals led me to new clues and, in other cases, to twists and turns. I got disoriented. I had to stop playing for a while because I did not understand anything. In some cases, I had to restart the level."
Review	"I have to check the clues and not open portals for the sake of opening them, as I will eventually lose perspective of the game and not know where I am or what I am doing."

Source: own elaboration.

Table 11. Procedures followed by students to pass the level following Polya's model (1989).

Phase	Explanation
Understanding the problem	"I have to open the exit door that will allow me to pass the level. To do this, I have to follow some clues, looking for them on the walls, objects, and in other rooms that make up the level."
Devising a plan	"I have to follow the clues and open the necessary portals to get to the exit door and open it."
Carrying out a plan	"After opening portals for a while, I do not quite know where I am anymore. I am disoriented and I do not know what to do anymore because I do not even know where the clues are."
Looking back	(Students do nothing)

Source: own elaboration.

Table 12. Procedures followed by students to pass the level following the model of Mason et al. (1992).

Phase	Explanation
Entry	"I must reach the exit door and open it to pass the level. I have to follow the clues that appear in the level."
Attack	"I opened portals so I could search for clues in the other rooms of the level. At the end, I had many portals opened and I saw someone moving, so to follow her I opened more portals and I did not know how to return. It made me disoriented, I got lost and did not know what to do."
Review	(Students don't write anything)

Source: own elaboration.

3.1. J11-Type Player. Player Who Does Not Need External Help to Pass a Level

The section below shows the J11- type player, the one who does not need external help to pass a level.

3.2. J21-Type Player. Player Who Is Stuck but Passes the Level without External Help

The section below shows the J21- Type Player, the one who despite being stuck, manages to pass the level without external help.

Two concepts described by Mason et al. [15] appear in this type of player: STUCK! when they start going around in circles opening portals following themselves, and AHA! when they return to solving the problem after getting lost between portals.

3.3. J31-Type Player. Player Who Gets Stuck on a Level and Does Not Continue

The section below presents the J31 type player, the one gets stuck on a level and doesn't continue.

Responses from the types of students who needed help (J12, J22, or J32) or who relied on their peers to advance in the video game have not been included. The answers they offered were very similar to those presented in Tables 7–12, except for the fact that they indicated they required help from their classmates in order to continue to advance in the video game.

Furthermore, by analysing the students' answers in Tables 7–12, we can see not only how the answers conform to the different phases described by Polya [14] and Mason et al. [15] but also how aspects related to mathematical problems appear, such as the statement of the problem, the data that appear, the unknown data, and the possible procedures to link the known and the unknown in order to pass the level, i.e., to overcome the challenge posed. These aspects are in line with the principles indicated by Chorianopoulos and Giannakos [28] that link video games and problem-solving. In the last block of the questionnaire, the students were given a series of statements where they were asked to indicate their degree of agreement (1 = Strongly disagree, 2 = Somewhat disagree, 3 = Somewhat agree, and 4 = Strongly agree) after having played and passed the different levels. The first statements were related to their feelings or emotions towards mathematical knowledge. The following statements were related to the video game and its use with respect to the resolution of mathematical problems. Finally, there were statements related to the emotions experienced during the activity.

The first statement (S1) they had to respond to was: 'Everything related to mathematical knowledge makes me feel overwhelmed or stressed'. Figure 2 shows that the majority of our students responded 'Strongly agree' to the statement (3.71 $\pm$ 0.25). This result was linked to the second statement (S2): 'When I do a task that involves mathematical knowledge, I feel nervous or afraid'. The percentages were very similar in both statements. Figure 3 shows that, once again, the students responded 'Strongly agree' (3.81 $\pm$ 0.26) to the statement about negative feelings that arise when solving any task involving mathematical knowledge. These behaviours, as Gómez-Chacón [31] indicates—citing different authors—are due to two fundamental aspects: beliefs and emotions; indicating that an important factor is how students learn and use mathematics, or how they see themselves as learners.

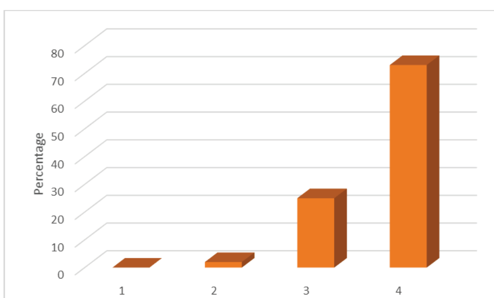


Figure 2. Students' degree of agreement with the stress or distress that mathematical knowledge causes them.

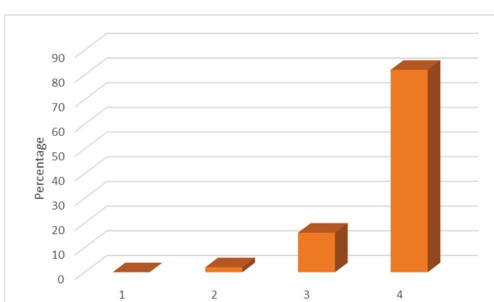


Figure 3. Students' degree of agreement with their negative feelings when carrying out a mathematical task.

The following statements from the questionnaire were related to the video game itself and its relation to problem-solving. The first statement (S3) was: 'To pass a level of the video game, I must apply the same phases as in problem-solving'. In this case, the students answered mostly 'Somewhat disagree' or 'Somewhat agree' (2.61 ± 0.17), as can be seen in Figure 4. The students indicated that the main aspect they saw in video games was the recreational aspect or that of diverting from reality, and that they did not think about whether or not the procedures were mathematical when passing a level. The procedures they used were those they knew to be effective in passing the level regardless of the type of game they were playing.

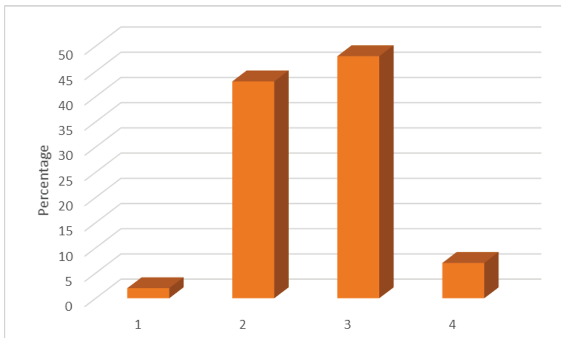


Figure 4. Students' degree of agreement with the use of problem-solving procedures to pass to the next level in a video game.

The fourth statement (S4) was: 'There is a relationship between the situation presented in the video game and solving mathematical problems'. The answers given by the students (Figure 5) show that they do not believe that there is a relationship between playing video games and solving mathematical problems. The students mostly disagreed with the statement, with the most popular response being 'Somewhat disagree' (2.08 ± 0.18). Similar to their answer to the previous statement, they justified this by saying that they viewed video games as a distraction to be used for recreational purposes rather than educational purposes. Few students found or justified relationships such as those shown by Chorianopoulos and Giannakos [28]. The students recognised that a problem arose that they had to solve, but it did not correspond to the type of problems they are used to solving in the different educational stages they have gone through.

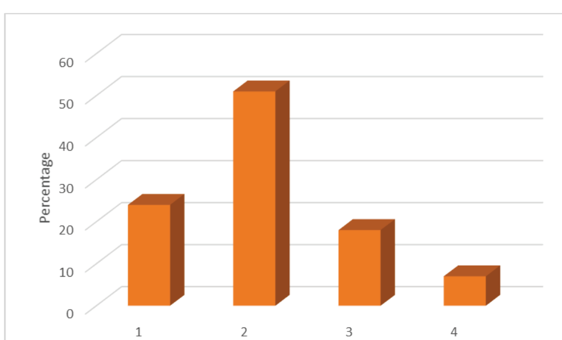


Figure 5. Students' degree of agreement with the comparison of the situations posed in a level of the video game with the situations posed in a mathematical problem.

The final statements that were put forward concerned the emotions or feelings that the students experienced during the game and compared them with those they experienced when solving a mathematical problem. The first of the statements (S5) was related to their emotional state when playing the video game: 'I felt good when playing the video game'. The majority answered 'Somewhat agree' (2.74 ± 0.17), as can be seen in Figure 6. Most of our students found playing the video game to be a pleasant experience that broke from the usual routine of the class. Once again, they highlighted that the recreational aspect of the video game lacked the pressure that accompanies regular classroom activities. However, there was a small number of students that responded 'Strongly disagree' to the statement. These students argued that they did not understand the game, that they got disoriented, that they did not manage to pass the level, and that, when they did, it was with the help of their classmates. The argument regarding the disorientation caused by the video game was also put forward by those who answered 'Somewhat disagree' as they felt it was easy to get lost and slightly difficult to refocus on the game.

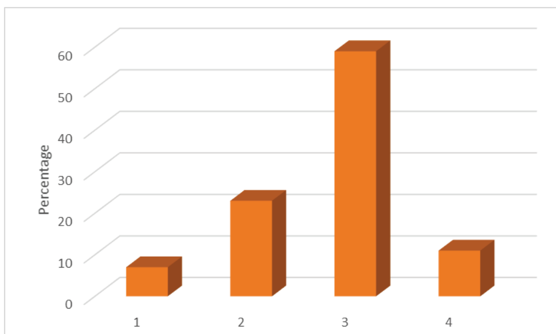


Figure 6. Students' degree of agreement with the emotions experienced when playing the video game.

The last statement (S6) was: 'The emotions I have experienced while playing the video game are the same as those I experience when solving a mathematical problem'. The students mostly disagreed with the statement (1.99 ± 0.19)—which was expected given their responses to the previous statement on the comparison of mathematical problem-solving and passing a level of the video game, as can be seen in Figure 7. Once again, the recreational aspect took precedence over the educational aspect. The students believed that the stress they suffered when carrying out any mathematical activity was not comparable to playing a video game.

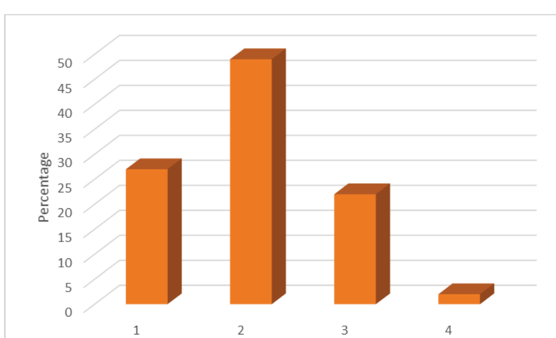


Figure 7. Students' degree of agreement with the comparison of emotions when playing a video game and when solving a mathematical problem.

Based on the data obtained from the Likert scale for each of the statements, we carried out a correlation analysis on the different statements, shown in Figures 2–7. As can be seen in Figure 8, the correlation between statements 1 (S1) and 2 (S2) shows a strong Pearson's correlation coefficient (0.81, $p < 0.001$), indicating that the students' negative feelings towards mathematical knowledge are transferred to any task that involves the use of such knowledge. This result could be justified by students' opinions such as "I am not good at mathematics" or "I do not like mathematics". Focusing on the second block of statements related to the use of video games and their relationship to problem-solving (S3 and S4), we also observe a strong Pearson's correlation coefficient (0.80, $p < 0.001$). Although both statements S3 and S4 relate video games and problem-solving procedures, when relating them to statements S1 and S2 from the previous block, we discovered that the relationship is no longer direct; instead, we observed an inverse relationship with a negative Pearson's correlation coefficient (S1 with S3, $r2 = -0.36$, $p < 0.001$; S1 with S4, $r2 = -0.40$, $p < 0.001$; S2 with S3, $r2 = -0.48$, $p < 0.001$, and S2 with S4, $r2 = -0.50$). As indicated above, the students mainly consider video games to be something fun, separate from mathematics, whose recreational aspect takes precedence over other aspects. Analysing the answers given to the last two statements (S5 and S6), we see that S5 shows a good correlation with S3 (0.55, $p < 0.001$) and with S4 (0.56, $p < 0.001$). This exhibits a direct relationship, as would be expected, since the recreational aspect of video games takes precedence over any other aspect, hence the positive emotions they elicit. However, when comparing S5 with S1 (-0.30, $p < 0.001$) and S2 (-0.35, $p < 0.001$), we see that there is an inverse relationship as the emotions related to mathematical knowledge are negative, while those related to the use of video games are positive, with the recreational and relaxing aspects of video games taking precedence. Statement 6 (S6), however, exhibits differences to all the previous statements. It presents very weak correlation values with a significance (p-value) greater than 0.1. This could be due to the fact that emotions are highly conditioned by the type of video game chosen and by the interests of the students themselves when playing a video game. Video game choice preferences manifest themselves as more complex relations, according to Ref. [32], and even vary from one time period to another [33]. The possible impact on video game players, their benefits, or their effects on behaviour and emotions must also be considered, as indicated by Ref. [34].

Correlation Matrix

		S1	S2	S3	S4	S5	S6
S1	Pearson's r	—					
	p-value	—					
S2	Pearson's r	0.808 ***	—				
	p-value	< .001	—				
S3	Pearson's r	-0.360 ***	-0.480 ***	—			
	p-value	< .001	< .001	—			
S4	Pearson's r	-0.399 ***	-0.502 ***	0.800 ***	—		
	p-value	< .001	< .001	< .001	—		
S5	Pearson's r	-0.300 ***	-0.352 ***	0.546 ***	0.558 ***	—	
	p-value	< .001	< .001	< .001	< .001	—	
S6	Pearson's r	0.103	0.065	-0.058	-0.102	-0.110	—
	[illegible]	[illegible]	0.403	0.451	0.186	0.152	—

Note. * p < .05, ** p < .01, *** p < .001

Figure 8. Correlation matrix and heat map shown in the statements (S1 to S6) shown to students.

4. Conclusions

Since they became a recreational–cultural element, video games have had a strong presence in people's daily lives. This means that video games can be used as a medium through which to build didactic experiences, or to be implemented as support tools in the classroom in order to generate learning. Although they were not conceived as a curricular tool, they can be used as a didactic element following a previous treatment and adaptation with respect to the teaching–learning process in which they will be employed.

The objective set out in this study involved aiming to take advantage of the potential provided by video games when analysing whether the techniques or procedures used to overcome a level in a video game are analogous to those used to solve a mathematical problem. We also aimed to analyse whether the situations posed by a video game can be equivalent to those described in a mathematical problem. Based on the results obtained in the answers given by our students, we can state that the students were not sure whether or not they were really using such procedures or whether they are comparable situations. That is, the students were not able to determine their applicability and theoretical transposition to a virtual context and vice versa. However, when describing the procedures they used to pass a level, they conformed to the procedures learned at school. They described in detail each of the phases they went through, which are equivalent to those described for problem-solving in the methods of both Polya [14] and Mason et al. [15]. These seemingly contradictory results lead us to believe that video games are perceived in a purely recreational sense, but the students were not able to discern their didactic potential. Moreover, from their answers, we observed that the feeling of stress or fear that any activity related to mathematical knowledge produces is still present during the problem-solving process.

Our second objective was related to the emotions that students experience when playing a video game and when solving a mathematical problem. We found that, in particular, the Portal 2 video game elicits mixed feelings. We found that there were students who had been challenged, which led them to become more involved in passing the levels despite the different tests and perspectives presented by the video game. That is, it provided extra motivation when facing the proposed challenge. However, other students stated that the movement through the levels of the video game—with recurrent changes of perspective—seemed quite complex to them as they were unable to orient themselves and even felt disoriented.

In conclusion, we can state that the procedures for solving mathematical problems and for passing a level in a video game are the same. However, unlike mathematical activities—which cause students to experience negative feelings—video games promote positive emotions. Video games are considered to be recreational, relaxing, and can provide a means of diverting from academic aspects as they are unrelated to the mathematical knowledge that causes students so much stress or feelings of fear.

The world of video games allows us to take advantage of all their potential for educational purposes by orienting them to work on knowledge that—despite being part of students' lives—causes them stress and uncertainty when using traditional methodologies and tools. For future lines of research, we could implement the use of video games as a tool to facilitate knowledge by creating a gamified environment in the classroom, as indicated in Ref. [35], in such a way as to encourage students' commitment and motivation towards mathematical knowledge.

Similarly, taking advantage of video games as a tool for working on logical–mathematical knowledge, we could gain a deeper understanding of the emotions that students experience when faced with logical–mathematical knowledge and whether the use of the video games modifies these feelings.

Author Contributions: All authors participated in the theoretical framework, data collection and analysis, and discussion. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Informed consent was obtained from all subjects involved in the study.

Informed Consent Statement: All students agreed to participate at the beginning of the research.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available at the participants' requests.

Acknowledgments: To the students of the 2nd year of the Early Childhood Education Degree at the University of Cadiz, Spain. Academic year 18/19.

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

References

1. McGonigal, J. *Reality Is Broken: Why Games Make Us Better and How They Can Change the World*; Penguin: Sidney, Australia, 2011.
2. Revuelta, F.I.; Guerra, J. ¿Qué aprendo con videojuegos? Una perspectiva de meta-aprendizaje del videojugador. *Rev. Educ. Distancia* **2012**, *33*, 1–25.
3. Gorgorió, N.; Albarracín, L. Mathematical knowledge prior to the Initial Education of Teachers: The need for and specification of a test for their evaluation. In *Research on the Mathematics Teacher: Training, Classroom Practice, Knowledge and Professional Competence*; University of Salamanca: Salamanca, Spain, 2019; pp. 111–132.
4. Beserra, V.; Nussbaum, M.; Oteo, M. On-Task and Off-Task Behavior in the Classroom: A Study on Mathematics Learning With Educational Video Games. *J. Educ. Comput. Res.* **2019**, *56*, 1361–1383. [CrossRef]
5. Moore-Russo, D.; Diletti, J.; Strzelec, J.; Reeb, C.; Schillace, J.; Martin, A.; Arabeyyat, T.; Prabucki, K.; Scanlon, S. A study of how Angry Birds has been used in Mathematics Education. *Digit. Exp. Math. Educ.* **2015**, *1*, 107–132. [CrossRef]
6. Tokac, U.; Novak, E.; Thompson, C.G. Effects of game-based learning on students' mathematics achievement: A meta-analysis. *J. Comput. Assist. Learn.* **2019**, *35*, 407–420. [CrossRef]
7. Anderson, J.; Barnett, M. Using Video Games to Support Pre-Service Elementary Teachers Learning of Basic Physics Principles. *J. Sci. Educ. Technol.* **2011**, *20*, 347–362. [CrossRef]
8. Croxton, D.; Kortemeyer, G. Informal physics learning from video games: A case study using gameplay videos. *Phys. Educ.* **2017**, *53*, 015012. [CrossRef]
9. de Aldama, C.; Pozo, J.-I. Do you want to learn Physics? Please play *Angry Birds* (but with epistemic goals). *J. Educ. Comput. Res.* **2020**, *58*, 3–28. [CrossRef]
10. Pittman, C. Teaching With Portals: The Intersection of Video Games and Physics Education. *Learn. Landsc.* **2013**, *6*, 341–360. [CrossRef]
11. Ullman, T.D.; Spelke, E.; Battaglia, P.; Tenenbaum, J.B. Mind Games: Game Engines as an Architecture for Intuitive Physics. *Trends Cogn. Sci.* **2017**, *21*, 649–665. [CrossRef]
12. Ministerio de Educación y Ciencia. Orden ECI/3960/2007, de 19 de Diciembre, por la que se Establece el Currículo y se Regula la Ordenación de la Educación Infantil. Boletín Oficial del Estado. 2008. Available online: https://www.boe.es/eli/es/o/2007/12/19/eci3960 (accessed on 13 December 2021).
13. Ministerio de Educación, Cultura y Deporte. Real Decreto 126/2014, de 28 de Febrero, por el que se Establece el Currículo Básico de la Educación Primaria. Boletín Oficial del Estado 2014. Available online: https://www.boe.es/eli/es/rd/2014/02/28/126 (accessed on 13 December 2021).
14. Polya, G.; Zugazagoitia, J. *Cómo Plantear y Resolver Problemas*, 15th ed.; Mexico, D.F., Ed.; Trillas: Mexico City, Mexico, 1989; ISBN 9682400643.
15. Mason, J.; Burton, L.; Stacey, K. *Pensar Matemáticamente*, 2nd ed.; Labor: Barcelona, Spain, 1992; ISBN 8433551396.
16. Quintanilla Batallanos, V.A.; Gallardo Romero, J. Identificar experiencias emocionales para mejorar la comprensión en matemáticas. *Uno Rev. De Didáctica De Las Mat.* **2020**, *88*, 24–33.
17. Di Leo, I.; Muis, K.R.; Singh, C.A.; Psaradellis, C. Curiosity ... Confusion? Frustration! The role and sequencing of emotions during mathematics problem solving. *Contemp. Educ. Psychol.* **2019**, *58*, 121–137. [CrossRef]
18. Caballero, A.; Blanco, L.J.; Guerrero, E. Problem-solving and emotional education in Initial Primary Teacher Education. *EURASIA J. Math. Sci. Technol. Educ.* **2011**, *7*, 281–292. [CrossRef]
19. Hanin, V.; Van Nieuwenhoven, C. Developing an expert and reflexive approach to problem-solving: The place of emotional knowledge and skills. *Psychology* **2018**, *9*, 280–309. [CrossRef]
20. Trezise, K.; Reeve, R.A. Cognition-emotion interactions: Patterns of change and implications for math problem solving. *Front. Psychol.* **2014**, *5*, 840. [CrossRef]
21. Hernández-Sabaté, A.; Albarracín, L.; Calvo, D.; Gorgorió, N. EyeMath: Identifying Mathematics problem solving processes in a RTS video game. In *Proceedings of the Games and Learning Alliance: 5th International Conference, GALA 2016, Utrecht, The Netherlands, 5–7 December 2016*; Springer: Cham, Switzerland, 2016; pp. 50–59.
22. Bavelier, D.; Green, C.S.; Pouget, A.; Schrater, P. Brain plasticity through the life span: Learning to learn and action video games. *Annu. Rev. Neurosci.* **2012**, *35*, 391–416. [CrossRef] [PubMed]
23. Blumberg, F.C.; Rosenthal, S.F.; Randall, J.D. Impasse-driven learning in the context of video games. *Comput. Hum. Behav.* **2008**, *24*, 1530–1541. [CrossRef]
24. de Aguilera, M.; Mendiz, A. Video games and education. *Comput. Entertain.* **2003**, *1*, 1–10. [CrossRef]
25. Shute, V.J.; Ventura, M.; Ke, F. The Power of Play: The effects of Portal 2 and Lumosity on Cognitive and Noncognitive Skills. *Comput. Educ.* **2015**, *80*, 58–67. [CrossRef]
26. Shute, V.; Wang, L. Measuring Problem Solving Skills in Portal 2. In *E-Learning Systems, Environments and Approaches*; Isaías, P., Spector, J., Ifenthaler, D., Sampson, D., Eds.; Springer: Cham, Switzerland, 2015; pp. 11–24. [CrossRef]
27. Avry, S.; Chanel, G.; Bétrancourt, M.; Molinari, G. Achievement appraisals, emotions and socio-cognitive processes: How they interplay in collaborative problem-solving? *Comput. Hum. Behav.* **2020**, *107*, 106267. [CrossRef]

28. Chorianopoulos, K.; Giannakos, M. Design principles for serious video games in Mathematics Education: From theory to practice. *Int. J. Serious Games* **2014**, *1*, 51–59. [CrossRef]
29. Creswell, J.W. *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*, 3rd ed.; SAGE Publications: Newbury Park, CA, USA, 2009.
30. Novak, E.; Tassell, J. Using video game play to improve education-majors' mathematical performance: An experimental study. *Comput. Hum. Behav.* **2015**, *53*, 124–130. [CrossRef]
31. Gómez-Chacón, I.M. Affective influences in the knowledge of Mathematics. *Educ. Stud. Math.* **2000**, *43*, 149–168. [CrossRef]
32. Vahlo, J.; Karhulahti, V.M. Challenge Types in Gaming Validation of Videogame Challenge Inventory (CHA). *Int. J. Hum. Comput. Stud.* **2020**, *143*, 102473. [CrossRef]
33. Qaffas, A.A. An Operational Study of Video Games' Genres. *Int. J. Interact. Mob. Technol.* **2020**, *14*, 175–194. [CrossRef]
34. Quwaider, M.; Alabed, A.; Duwairi, R. The Impact of Video Games on the Players Behaviors: A Survey. *Procedia Comput. Sci.* **2019**, *151*, 575–582. [CrossRef]
35. Tan, D.Y.; Cheah, C.W. Developing a gamified AI-enabled online learning application to improve students' perception of university physics. *Comput. Educ. Artif. Intell.* **2021**, *2*, 100032. [CrossRef]

MDPI
St. Alban-Anlage 66
4052 Basel
Switzerland
Tel. +41 61 683 77 34
Fax +41 61 302 89 18
www.mdpi.com

Education Sciences Editorial Office
E-mail: education@mdpi.com
www.mdpi.com/journal/education

MDPI
St. Alban-Anlage 66
4052 Basel
Switzerland

Tel: +41 61 683 77 34
Fax: +41 61 302 89 18

www.mdpi.com

ISBN 978-3-0365-3539-5