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Article

Geometry with a STEM and Gamification Approach: A Didactic Experience in Secondary Education

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Abstract: Recent societal changes have meant that education has had to adapt to digital natives of the 21st century. These changes have required a transformation in the current educational paradigm, where active methodologies and ICT have become vehicles for achieving this goal, designing complete teaching sequences with STEM approaches that help students to learn. Under a gamified approach, this document addresses a didactic proposal in geometry focused on STEM disciplines. This proposal combines tools such as AR, VR, manipulative materials, and social networks, with techniques such as m-learning, cooperative-learning, and flipped-learning, which make methodological transformation possible. The research was carried out during two academic years under an action research framework. It departed from a traditional methodology and, in two cycles, methodology was improved with the benefits that gamification brings to STEM proposals in Secondary Education. The data gathered in the experiment were analysed following a mixed method. Learning produced, strategies employed, successes and errors, and results of a questionnaire are presented. Evidence shows an improvement in academic performance from 50% fails to 100% pass, most of the students ended up motivated, participation was of the whole group, more than 80% showed positive emotions, and thanks to the cooperative-learning, group cohesion was improved.

Keywords: geometry education; STEM; gamification; ICT; action research; virtual reality; augmented reality; breakout EDU; motivation

MSC: 97G40

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1. Introduction, Theorical Framework and General State of the Field

This study aims to show the design of a STEM (Science, Technology, Engineering, Mathematics) didactic sequence in mathematics. For this purpose, a theoretical foundation is made, in which, on the one hand, there are ICT (information and communications technologies) as educational support tools, and on the other hand, active methodologies. ICT that form part of these didactic proposal are augmented reality (AR), and immersive virtual reality (VR) simulators, to help the purpose of improving spatial visualisation skills in mathematics. In addition, a social network for educational purposes is used. Regarding active methodologies, gamification is used as the main methodology with its elements (points, rankings, and badges) and types, such as game-based learning, serious games (e.g., Classcraft) or Breakout EDU (Breakout educational). For its implementation in the classroom, gamification is supported by other active methodologies such as cooperative learning, flipped learning and m-learning (mobile learning). Finally, experiences from similar studies are presented.

The STEM approach aims to provide an integrated learning and training process so that students can acquire skills to help them meet the challenges of the 21st century [1]. This requires the didactic design and implementation of activities in the subject of mathematics to create an interdisciplinary connection with science, engineering, and technology [2].

1.1. ICT as Educational Support Tools

The rapid evolution of the latter allows the incorporation of ICT in the classroom, enabling a change in traditional teaching models [3].

Augmented reality is defined as software that offers the possibility to develop objects in a virtual environment without the need to physically have the objects [4]. Augmented reality, among other ICT [5], can be combined with m-learning techniques without the need to use a computer, using smartphone apps and QR codes [6]. Virtual reality simulators are defined as a technological environment that simulates reality but in a virtual world whose objects exist and can be manipulated only in the computer [7]. Immersive three-dimensional environments are places and objects that are represented graphically in three dimensions in a ubiquitous environment, where creativity and the development of interactive learning experiences are promoted by immersing the user in a virtual world which resembles reality [7,8]. VR simulators help the purpose of improving spatial visualisation skills [9]. These tools have proven to be effective for geometric training, part of its success is due to the possibilities it offers students to learn from their mistakes in a controlled environment, giving them autonomy in constructing their learning [10]. Numerous papers highlight visualisation as the cause of much learning difficulty and as a major source of error in geometry [11,12]. In addition, several studies support the use of new technologies and the search for innovative learning environments that connect with the current interests of students, leading to the use of dynamic geometry programmes aimed at the development of space-geometric skills as necessary components in mathematical tasks and the correction of errors [13–16]. Thus, with the emergence of augmented reality or virtual reality, visualisation errors can be alleviated. Research by [17] concludes that the advantages of working with virtual learning environments are: decision-making, increased creativity, improved visualisation, and hand-eye coordination.

Social networks are a tool that help to establish the foundations of a global and connected education for digital citizens; there is a predisposition of students to connect to social networks outside the educational environment, so the potential offered by these networks for teaching environments can be exploited [18].

In the 21st century, augmented reality, social networks and immersive digital virtual environments in the mathematics teaching-learning process are necessary for a methodological change to take place. Active methodologies enrich the teaching-learning process [3]. Moreover, as [19] points out, these active methodologies are based on a constructivist approach offering pedagogical benefits to learning.

1.2. Active Methodologies

One of these active methodologies, which is becoming increasingly prominent in the classroom due to its multiple benefits, is gamification. The challenge lies in integrating it into the classroom to make learning more fun [20]. Gamification allows using games or game elements in non-game situations to motivate the targets toward a specific point of interest [21–23]. In [24], the authors propose a pyramidal model in which the elements that make up gamification are organised hierarchically, explaining the existing relationship between all of them. Thus, the components or elements (avatars, badges, points, levels (rankings), etc.) are at the base. In an intermediate step, the mechanics are defined through challenges, rewards, etc. Finally, at the top, the dynamics encompass the narrative, progression, emotions, and relationships of the participants in the gamified process. This constitutes a fundamental technique in motivating the teaching-learning process instead of traditional methods [25]. On the other hand, challenges proposed by gamification cause students to seek to surpass their own goals, thus making the activity an example of self-improvement [26]. As part of gamification strategies, game-based learning methodology (GBL), serious games, or Breakout EDU can be used.

Game-based learning (GBL) is the use of games as tools to support learning, assimilation or assessment [27]. Serious games are games designed with an educational purpose rather than for entertainment purposes, they are especially effective for learning specific skills, from learning mathematics to learning a new language [28]. Serious games can be used for teaching various educational subjects [29], such as: sustainability (introducing sustainable development issues in computer science education: design and evaluation of the eco jsity game) [30]; computer programming (an interactive serious mobile game for supporting the learning of programming in javascript in the context of eco-friendly city management) [31]; robotics (advances in the use of educational robots in project-based teaching) [32]; gamified educational platforms (software that allows gamification elements (points, badges, and leaderboard) to interact with students in the learning process) [33]; or geometry experiences, with software such as NeoTrie VR [34]. According to [35,36], Breakouts EDU consists of the resolution of a series of enigmas or tests by a group of people who collaborate and whose ultimate purpose is to reach a goal. According to [37], in this type of dynamic, students are more committed to learning, favouring motivation and, consequently, the assimilation of the contents.

For a gamification strategy to be successful, as [38] argues, the aim is to create a structure of cooperative aspects that can keep students learning regardless of their initial level. For this reason, it is essential to create cooperative groups in order to develop each of the proposed dynamics. According to [39], cooperative learning is defined as the instructional use of small groups to enable students to work together and make the most of both self-learning and peer learning. In cooperative learning, peer groups can positively influence learning and social skills development [40]. Posing learning achievements as a challenge for learners to attain cooperatively, accompanied by an attractive design, has become an effective methodological strategy to reach the proposed objectives [41].

To free up time in the classroom and develop activities practically, it is necessary to transfer theoretical content to the home; this is achieved by deploying the main advantages of the flipped learning model [42]. Flipped learning is a pedagogical model in which the traditional classroom roles are inverted; the students take a central and active role, increasing their levels of motivation, autonomy, reflection, and the relationship among equals. In this model, the teacher acts as a guide in the process, turning the classroom into a dynamic and interactive learning space [43–46]. Furthermore, research such as that of [47–49] show that flipped learning integrates gamification and m-learning techniques very well, generating greater interest in the didactic sequence on the part of the students.

The study by [50] demonstrates the numerous benefits of integrating gamification into STEM processes. According to [51], gamified environments influence and improve motivation and encourage involvement in the dynamics proposed. Among their conclusions, they highlight the levels of motivation with a high incidence of commitment, the immersion in the process that facilitates anticipation and situation planning, and the socialisation of the group class. Experiences such as that of [52–54] show that 75% of the students were highly motivated in developing the gamified experience and highly satisfied with the usefulness of the proposed activity in their learning process, offering this experience as a didactic strategy. In their study [55], point out a cause-effect relationship between motivation and learning through gamification, and that four fundamental variables appear in gamified experiences: motivation, learning, attitudes, and flow. Subsequently, [56] describes the emergence of five categories in gamified processes: motivation, group cohesion, academic performance, emotions, and participation. Research by [57,58] show how the use of gamification with a STEM design approach improves the attitude toward mathematics by developing the students' interest and creativity, and what may be even more important, avoiding the fear of error, so that it becomes an opportunity to strengthen the concept and not a failure, as stated by [59].

Furthermore, studies carried out by [60–63] provide information on the benefits and difficulties that gamification processes generate in mathematics students.

Several factors must be developed for motivation to emerge in a gamified STEM design. As indicated in their studies [64–66], an interest in learning leads to subsequent academic performance and the acquisition of competences and skills. In addition, as [67] points out, novelty, fun, and discovery are also important. For [68], participation cannot be missing, and, finally, [69] indicates that it is essential to have an interactive educational platform, thus transforming technology into the vehicular language of gamified systems [70,71]. The goal of any gamified process is to achieve intrinsic motivation. According to [72,73], motivation has a relevant role in education. The concept of motivation refers to the interest shown in performing the activity for the pleasure obtained from the exercise itself, obviating external rewards or prizes (extrinsic motivation). According to research carried out in mathematics in Secondary Education by [74,75], intrinsic motivation derives from the students' self-efficacy in having confidence in their own abilities, positive emotions towards the tasks they are performing and the knowledge to achieve a goal, and this leads to effort, persistence, and peer-support behaviour. In their study, [76] state that intrinsic motivation in mathematics is related to the type of classroom activities and their relationship with active methodologies resulting in longer-lasting learning of the concepts covered. In his research in the mathematics classroom, [77] concludes that if students manage to have fun with the activity they are engaged in and forget about the time that passes, motivation changes from extrinsic to intrinsic. As stated by [78,79], in mathematics, it is essential to create an environment of play and related activities to develop extrinsic motivation and lay the foundations for intrinsic motivation to emerge in students with the continuation and improvement of the process. Experiences such as [80–82] in mathematics, and more specifically in the area of geometry, demonstrate the relationship between carrying out a mathematical gymkhana (team competition) through clues to solve a final group test with the learning goal set, making the extrinsic motivation flourish not only by obtaining the rewards but also the intrinsic motivation to solve problems in a way that was not even posed, a priori, by the methods seen in class. According to [83], motivation due to internal (emotions) and external (immersive tools) factors lead us to act to achieve a set goal. According to [84], student engagement increases significantly when they are motivated, often even choosing to continue with the activity at the end of the class, thus making learning more autonomous and meaningful. What excites also creates a significant imprint and, therefore, assimilation of what has been carried out. The reward is sought through the realisation of the activity itself rather than the final result of it [85]. As stated by [86], it is necessary to seek not only the students' extrinsic motivation through the rewards of points and badges in gamified environments, but also intrinsic motivation. In fact, the aim of any gamification strategy in the classroom should be to achieve intrinsic motivation of learners, i.e., to activate the desire to continue learning through the engagement of attention and interaction that gamification dynamics offer in the form of rewards, status, achievements, and competitions. The motivational nature of using gamification in the classroom has been shown to potentially influence attention, meaningful learning and student autonomy [87].

2. Materials and Methods

In this experience, we have employed a research methodology that can bring about educational change, where the figure of the researcher is also linked to that of teaching. Action research fits into this paradigm as one of the most appropriate ways to study, analyse and improve educational practice. Kurt Lewin described action research as a spiral process with self-reflective cycles with four stages each cycle: stage 1, exploration and observation; stage 2, diagnosis and planning; stage 3, action; stage 4, evaluation of the results of a classroom intervention in order to produce changes [88].

The experience presented was carried out in two action research cycles of four phases each, and its fundamental axis is to provide the design and assessment of a didactic proposal with a STEM approach based on gamification techniques. At the starting point, Point 0, after the initial observation, it was observed that when working on geometry in the subject of mathematics in the second year of ESO (i.e., compulsory secondary education), pupils in a traditional framework were demotivated and had significant learning difficulties (see Section 3.6). In the planning phase, an initial gamified STEM model was designed and implemented, supported by flipped learning and collaborative learning. After the action and a subsequent analysis, this model was improved in the next cycle of the action research carried out in the mathematics subject in the 3rd year of ESO. To this end, a gamified STEM model was redesigned, using flipped learning and cooperative learning as complementary methodologies to support the design.

2.1. Objective and Research Questions

This study aims to demonstrate that using the gamified STEM model, supported by educational platforms and ICT to work on geometry in secondary education, improves motivation, academic performance, participation, emotions, and group cohesion of students, taking into account the diversity of the classroom, as well as contributing to an improvement in student assessment tools.

The main objective of this study is therefore to answer the following research questions:

RQ1: Is academic performance improved by using a mathematical STEM didactic proposal supported by the Classcraft educational platform with active methodologies?

RQ2: Does the use of ICT supported by a gamified didactic proposal lead to increased student motivation and participation?

RQ3: Does a gamified STEM didactic proposal supported by cooperative learning improve student group cohesion?

2.2. Population and Sample

This experience was carried out over two consecutive years at the Juan de la Cierva Secondary School in Vélez-Málaga (Spain). The research involved the same class group of students. In the first period, 28 students took part, 16 girls and 12 boys in the 2nd year of ESO, aged between 13 and 15. Among the students, one had accumulated many absences, one had hyperactivity disorder, and other one had behavioural disorder. In addition, five of the students were repeating a grade, and two of them were diagnosed with high abilities. In the second period, 30 students participated, 17 girls and 13 boys, in the 3rd year of ESO, this time aged between 14 and 16. Although the same group as last year, an additional two students had emigrated from other schools. The gamified process was carried out in the first cycle with the Edmodo educational platform, supported and assisted by external elements such as the "*Matemático*" exercise programme for students' feedback and the external scoring system through playing cards. After analysing the advantages and disadvantages of this platform [89], in the second action research cycle we opted for the Classcraft platform. In addition, in this second cycle, two virtual reality equipments were used, so that, in some sessions, the class was divided into two groups. Group 1 consisted of 10 students who carried out some activities using the virtual reality tool (NeoTrie VR). Group 2 consisted of the remaining 20 students who used traditional manipulative materials during these sessions. Within these groups, cooperative teams of five students were formed in the second cycle of action research. Following an observation of each student's behaviour in the first cycle of action research, in the second cycle, roles characteristic of cooperative learning was assigned to each team member. In addition, these roles were found to be analogous to some on the Classcraft educational platform, as detailed below in Section 2.4.2.

2.3. Tecniques for Collecting Information

In order to obtain the relevant information on the teaching-learning process, the following instruments were used: participant observation by the teacher-researchers; data from the Classcraft educational platform; Kahoot! Statistics; an analysis of documents (teacher's diary and Classcraft's chat, where the comments and perceptions made by the students during the sessions are collected); assessment of individual and group activities; and a questionnaire with four levels on the Likert scale (Appendix A).

2.4. Action Research Cycles

2.4.1. First Action Research Cycle

It was observed after the first stage of observation in the 2nd year of ESO group, (see Section 3.6 for more details), that the students' low academic performance, as evidenced by the ratings obtained with more than 50% of students with fails grades, included: low motivation (only 30% of the students brought their homework with them, and of the 28 students, only five went to the blackboard to correct their homework and participated actively in the classroom if the teacher asked a question, the rest did not pay attention to the explanation and said they did not understand it or said they were bored in class); absenteeism (one student had accumulated a large number of absences and had only attended 30% of the classes for the entire academic year); lack of time in the classroom for practical tasks (as traditional methodology is taught in class, in the 60 min a session lasted, 50–55 min were dedicated to the theoretical explanation, leaving only 5–10 min to do exercises or to correct homework); as well as difficulty in dealing with diversity (in the group class there were students with hyperactivity disorder and behavioural disorders, which were difficult to deal with using traditional lecture methodologies). An approach to the gamified STEM model was planned and designed (second stage) and implemented (third stage), based on the assumption that this model, together with flipped learning and collaborative learning techniques, could substantially improve the aforementioned aspects. This first action research cycle was characterized by the fact that the students had not previously used the gamification methodology in conjunction with the learning platforms and ICT.

During the planning stage, it was decided to use the educational platform Edmodo, which allows students to submit their homework and the teacher to award badges, but lacks a scoring system or other gamified elements. In the action stage, the teacher provided feedback through a chat on the Edmodo platform, wherein each student, individually or in groups, could express their thoughts and doubts. These doubts were then resolved by both the teacher and the rest of the students via chat or within the first few minutes at the start of the following class session.

On finalizing the dynamics proposed in the classroom sessions, the teacher designed, created, and awarded badges as rewards (an element of gamification) through the individual interface of each student in Edmodo, although the platform also offered the possibility of awarding badges in groups [89]. The scoring process was done externally to the platform using cards containing points and powers that students could use throughout the sessions (Figure 1).

Figure 1. Cards with points, polyhedral, and powers.

The proposal was carried out with a topic of geometry, specifically, geometric proportionality: symmetries, scales, Pythagoras' theorem, and Thales' theorem. The work on game-based learning began with an approach to the STEM model with small brushstrokes.

As per [90], 12 sessions were designed and programmed, detailed in [90] publication, including gamification techniques, and were supported by m-learning techniques. The mathematical tasks set in the classroom prioritised group and collaborative work. There were challenges involving demonstrations of geometric theorems with puzzles (Tangram) and manipulative materials, the building of models to scale, and a game played to measure inaccessible heights in the form of an escape room. In one of the tests, students had to put into practice elements of physics, such as the reflection and refraction of rays through a mirror to calculate heights. Finally, by way of assessment, a mathematical gymkhana (team competition in a treasure hunt) was held in the historic center of the municipality dealing with art, geography, and its history, all in the context of a series of activities highlighting the functional and educational nature of mathematics, supported by technological elements, such as interactive maps with multimedia elements, accessible via mobile phones and QR codes with challenges and instructions (see https://bit.ly/2UMtfHs (accessed on 4 May 2018)).

Following the development of this proposal, and after a process of reflection and evaluation (fourth stage of the first action research cycle), a series of shortcomings in the model were observed. These shortcomings will be discussed below and showed the need to fulfil the STEM model by completing the interdisciplinary nature of the contents dealt with in other subjects, as well as improving the gamified process through a new educational platform. Thus, it was proposed to look for another educational platform to overcome the difficulties found in the Edmodo platform, particularly the lack of a score system and other elements to complete a gamified system, while maintaining its virtues. The new platform needed to have the possibility of more significant student interaction within the platform environment, without needing to resort to applications or game cards with scoring and external powers using an external scoring system. The Classcraft platform was the platform of choice, as the game tools and the integration of multimedia resources offered more possibilities to carry out the gamified STEM model. In addition, due to the avatars' aesthetics and the interface, this platform is more conducive to secondary school students [91].

2.4.2. Second Action Research Cycle

The second action research cycle was carried out one academic year later, in the third year of ESO, with the same class group as in the first cycle.

The gamified STEM model was utilized in 12 sessions with a geometry block theme in the design and implementation stage. In this case, the topics were related to geometric solids: classification of polyhedra, Platonic and Archimedean solids, Euler's theorem, construction of duals, planes of symmetry, and axes of rotation. These sessions included an initial critical assessment to detect difficulties and errors [92] and a final assessment consisting of a Breakout EDU with a STEM focus, with a nod to the female references of women who excelled in geometry and specifically in the study of polyhedra, and specifying each session of the proposed didactic design, highlighting its techniques and tools.

All these activities and dynamics were designed with the interests of the class group in mind and with a STEM approach, with a particular focus on developing spatial visualisation skills in geometry. The contents covered are based on the LOMCE (2013) Spanish curriculum, which was in force at the time of the proposal, and the criteria of the NCTM (National Council of Teachers of Mathematics) (2000).

To shape the STEM gamified process, the Classcraft platform, Figure 2, was used as the game scenario.

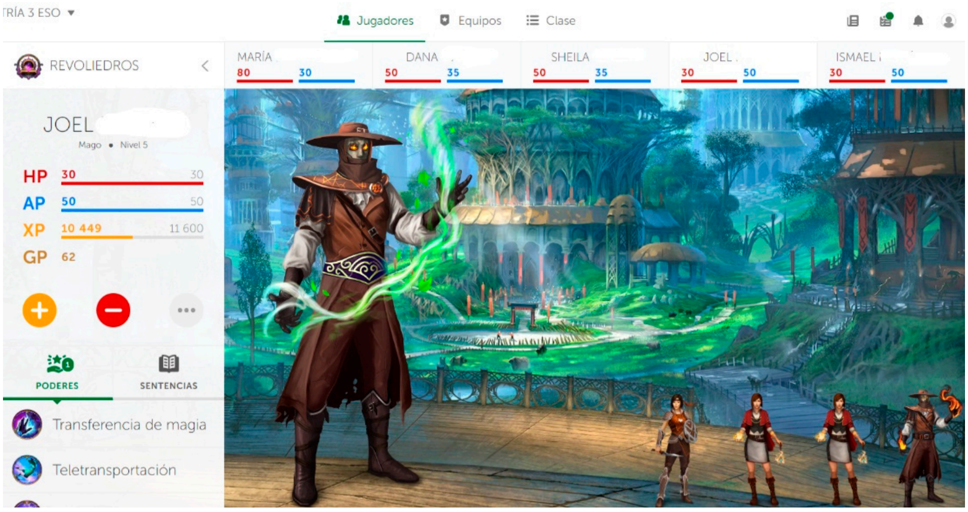


Figure 2. Aesthetics of one cooperative group in Classcraft.

In this game scenario, students can award points (HP, AP, XP, and GP): health points (HP) are given for well-done activities; ability points (AP) are used by students to activate powers; experience points (XP) are extra points for good behaviour or for accumulating HP and allows them to level up; and gold pieces (GP) are badges that could be transformed into powers that students could use in class or to obtain virtual object or mascots. The platform's point score mechanics are described using an interactive machinations diagram (Figure 3) (for example, in this simulation, at a cost of 10 points, is considered to obtain each virtual mascot and avatar's object; a cost of 30 points obtains each power; and there is a cost of 50 points to level up. Also for simulation, it was considered that students could buy more avatar add-on than powers with GP). A dynamic diagram can be viewed at https://bit.ly/3QPBKPa (accessed on 20 August 2022).

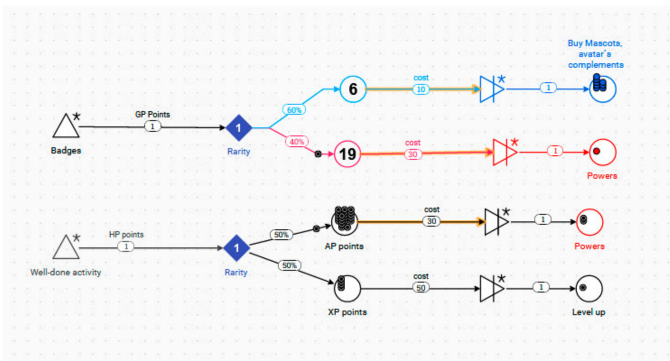
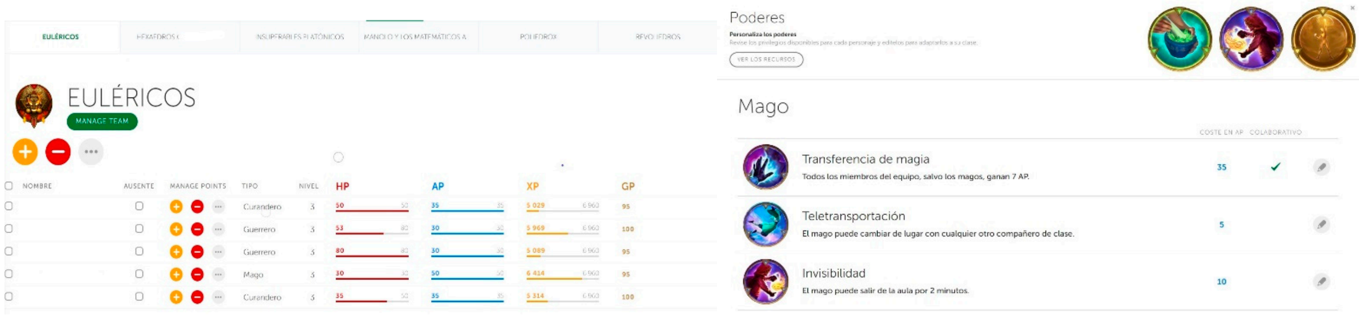


Figure 3. Capture of a moment of the simulation of point acquisition (diagram in "Machinations", symbols equivalence: triangle = source; circle = pool; triangle with line = converter; rhombus = gate).

Leader boards are established as students gain points in cooperative teams and by the whole group in a class, as shown in Figure 4 (see Section 3.1 for more details).



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

Figure 4. (**a**) leader board of one of the cooperative groups; (**b**) powers from wizards in Classcraft.

As explained by [93], the students could create their own avatar on the platform and interact with it, establishing a similarity between the role given within the cooperative learning methodology (coordinator, secretary, etc.) and the characteristics and role played by the avatar on the platform (magicians, warriors, healers). The following table (Table 1) shows the relationship established between the cooperative learning roles and those adopted on the Classcraft platform, the criteria followed by the research teacher for assigning the former, and the percentage of coincidence between the two.

Table 1. Relationship between cooperative learning roles and Classcraft roles.

Cooperative Learning Role	Assignment Criterion	Objective	Avatar on Classcraft	Percentage Match Cooperative Role/ Avatar Role Classcraft
Coordinator	Responsible, well-developed academically and empathetic pupils.	Manage the work and the team, but always taking everyone's opinion into account.	**Healers** (recovering lives in the game, responsible role, students with good academic results).	100%
Assistant or person in charge of equipment	Students who demonstrated creative skills.	Help choose the materials to be used during the experience.	**Wizards** (Maintains team powers and skills, role with socialisation problems, shyness). **Healers**	83% 17%
Secretary	Restless, disruptive pupils.	Establish habits by being accountable for work to peers.	**Warriors** (Defend the team, active role).	100%
Controller	Less attentive pupils.	Promote an atmosphere of concentration and responsibility.	**Warriors** **Wizards** **Healers**	66.7% 16.7% 16.6%
Spokesperson	More shy and reserved pupils, with less social interaction.	They relate Unwittingly through its role with the rest of colleagues.	**Wizards**	100%

Source: Own elaboration [93].

As shown in Figure 5, the Classcraft platform offered maps with the route, and proposed challenges to be overcome. There were four islands on the Classcraft world map, each corresponding to a part of the experience. Each island offered a challenge (Table 2), and the work sessions related to this challenge were linked to the challenge's narrative and resolution. To better understand the complete didactic proposal, an interactive reproduction of the Classcraft maps have been made with Genially and can be viewed at https://bit.ly/3AtNEbY (accessed on 5 September 2020).

Figure 5. Map with the proposed challenges and sessions in Classcraft.

In each session, points could be awarded by the teacher-researcher, up to 1000 points per student for each session, based mainly on academic performance according to each student's success in the challenges and dynamics, although some points were also awarded for help, group work, socialisation, and interest shown in the other members of the team. In total, the 12 sessions accounted for 12,000 HP points.

On the other hand, establishing a flipped learning model that allowed the content to be transferred to the case through viewing videos, left time for using active methodologies combined with ICT tools in the classroom. Among these tools, we highlight augmented reality using mobile phones with QR codes [94], and the dynamic geometry software in an immersive virtual reality environment, NeoTrie VR, which allowed for constructing polyhedra and analysing their characteristics.

The following (Table 2) were the proposed challenges, mostly weekly, and the sessions that took place in parallel.

The 12 sessions are described below (Table 3). They are based on the structure presented by the research of [24] concerning elements, mechanics, and dynamics. Some of these 12 sessions have been published in greater detail in other publications and are accompanied by the corresponding references.

Table 2. Challenges and parallel sessions.

First Challenge	**Parallel Sessions**
The first challenge was to find polyhedra in the real world and everyday life, to bring some of these polyhedra from home to the classroom as they would be part of the activity of classifying geometric solids and the activity of inducing Euler's theorem.	Sessions 2–4
Second challenge	**Parallel sessions**
The second challenge of this experience coincided with the Easter break and was launched in the holiday period. It consisted of using the social network Twitter, and each student had to tweet polyhedra that they saw in the real world with a photo, according to a series of hashtags and specific rules for retweets and likes [95].	Session 5

Table 2. *Cont.*

Third and Fourth challenge	Parallel sessions
Given that there was an exhibition about women in science, technology, and mathematics, in every corridor of the school, which had gone unnoticed by the students for years, the third challenge was the search for such women. The fourth challenge occurred at the end of Sessions 8–10, with a dynamic to build polyhedra through shadows. The shadows created with the light of the projector and the hands of the different members of each group tried to form the different geometric solids.	Sessions 6–11
Fifth challenge	**Parallel sessions**
The fifth challenge was a competition involving the creation of a video presentation with the theme and narrative for the start of the Breakout EDU. This competition was submitted to a vote by the students, and the video was chosen at the start of Session 12. It was the final challenge before facing the final assessment.	Session 12

Source: own elaboration.

Table 3. Session design, second action research cycle.

Session 1: Initial Assessment [92]
Elements
Depending on whether the answers are correct or not, a scoring system is assigned so that students can interact with the platform and their Classcraft avatars, virtual mascots, and powers.
Mechanism
1. The challenge called "Miniboard" consists of answering questions from an initial assessment questionnaire [92] on "Miniboards" on plastic sheets (Figure 6). 2. The "Speed dating polyhedral" challenge is done in pairs and through mime. The polyhedra seen on a card chosen randomly are described, and the other person must guess which one it is.
Dynamics
1. "Miniboard" shows the pupils' mistakes and difficulties when dealing with the subject of geometric shapes. The answers are then fed back to the teacher-researcher and the rest of the class. 2. "Speed dating polyhedral" demonstrates the level of visual skills of the pupils.
Session 2: Classification of geometric solids
Elements
Group 1 used the virtual polyhedron pieces that appear in the NeoTrie VR immersive environment, while Group 2 used wooden polyhedron pieces (Figure 7). Points were awarded in Classcraft based on each team member's success in ranking the different classification categories.
Mechanism
Students classify different geometric solids according to various criteria or categories of analysis in two phases.
Dynamics
In the first phase, the students determine the classification criteria (e.g., number of faces, vertices or edges, shapes of the polygons of equal faces, etc.). In a second phase, the students classify the shapes according to the criteria given by the teacher-researcher (e.g., regular, and irregular polygons, number of dihedral angles, etc.).
Session 3: Regular polyhedra
Elements
Classcraft scoring, allocation of powers according to the number of regular polyhedra constructed. Polydron game. Virtual reality tool NeoTrie VR.

Table 3. *Cont.*

Mechanism Group 1 used the immersive environment NeoTrieVR, while Group 2 used the polydron game as manipulative material. Students determined the number of regular polyhedra.
Dynamic The students built the shapes until they could close them and make a regular polyhedron. Some students completed five platonic solids, while the remaining were irregular or remained open.
Session 4: Analysis and deduction of Euler's theorem
Elements The Classcraft score depends on the correctness of the student's analysis of the polyhedra (virtual, wooden, Zome game). Students who could induce Euler's formula and write it on the worksheet were awarded an extra power as a badge on the Classcraft platform.
Mechanism Analyses the number of faces, edges, and vertices of polyhedra. Based on the examples anlyzed, induce the formula of Euler's theorem
Dynamic With the help of wooden or virtual polyhedra and a fillable card, students indicated the number of faces, edges, and vertices of each, and after a process of investigation and analyzing numerous examples, some induced the formula of Euler's theorem.
Session 5: Research works [96].
Elements Classcraft scoring, badges according to work done.
Mechanism The options, after research and documentation of each proposal, were: to build an origami of a known polyhedron; to create a video about polyhedra that can be found in nature, art, science, and human constructions; to create a drawing or work of art about polyhedra in three dimensions if possible; to create a video game or digital quiz about polyhedra in nature, art, science, and human constructions (Figure 8).
Dynamic Upon their return from the Easter holiday break, each student presented their research work carried out during their break to the rest of the class. Each member of the cooperative learning team produced material based on their research concerning polyhedra, which would form part of the presentation.
Session 6: Game-based learning
Elements A series of self-created manipulative games adapted to the content covered were used, combining math questions and the art, nature, and science content shown in the work of Session 5. The games included a "who's who" memory game, Pictionary, and a quiz game (Figure 9). Participants received a Classcraft score depending on the correct answers.
Mechanism Play the games and rotate them every 10 min between teams.
Dynamics These games combined geometry questions about polyhedra that appear in nature, art, science, and human constructions, some of which appeared in the research videos shown in the previous session (viruses, molecules, minerals, polyhedra in sculptures, paintings, buildings, album covers, and the animal world, etc.).
Session 7: Game development, design, implementation, and testing
Elements Card with rules, dynamics, mechanics, elements, and blank board to design the game. In this case, the students themselves awarded the Classcraft points according to how they considered that the rest of their classmates had interacted with the game created by each team, and how fun and useful it was.

Table 3. *Cont.*

Mechanism The students created a game on blank boards by adding their dynamics, game rules, and whatever else they felt was needed to create a game with the same STEM focus as in the previous session (Figure 10).
Dynamic Once they had been created and implemented, each team tested the boards of the other groups.
Session 8: Symmetry planes and duals.
Elements Classcraft scoring. Virtual reality simulator tool NeoTrie VR. Zome Game.
Mechanism Construct the planes of symmetry and the dual polyhedra of platonic solids.
Dynamics Group 1 drew the symmetry planes and the dual polyhedra with the virtual reality tool NeoTrie VR. Group 2 used the hollow methacrylate pieces and cardboard to manipulate the planes and the Zome game to make the dual polyhedral (Figure 11).
Session 9: Truncated polyhedra or Archimedean solids [94].
Elements Scoring on the Classcraft educational platform. Polydron game. Sheet of paper with truncated polyhedra. Smartphone and QR codes. An augmented reality application. Badges and powers to use with avatars on the platform.
Mechanism The whole class group construct Archimedean solids (truncated polyhedra) from augmented reality figures with manipulative material polydron (they could also be seen in the sheet of paper).
Dynamic Visualize the different truncated polyhedra with the augmented reality mobile application by reading QR codes. Replicating these polyhedra with the pieces of the polydron set (Figure 12).
Session 10 and 11: Axes of rotation of regular polyhedra
Elements Scoring in Classcraft. Virtual reality simulator tool NeoTrie VR. Badges and powers to use with avatars on the platform.
Mechanism Construct the axes of rotation of regular polyhedra (platonic solids) with NeoTrie VR.
Dynamic The axes of rotation were made using the NeoTrie VR tool by the whole class in two consecutive sessions. Simultaneously, a dynamic with the Kahoot! tool was also created to review the contents given during the subject.
Session 11: Review Kahoot!
Elements Kahoot! game
Mechanism Using a mobile phone and clicking on the game link in the application, each student participates by registering with a code provided by the teacher.
Dynamic Digital quiz (Appendix B) pointing to one of the four options offered by the class digital whiteboard, on their mobile phone. The student with the highest score for the most correct answers wins. The game application establishes a ranking of the top three and provides statistics on the correct answers given by each student.

Table 3. *Cont.*

Session 12: Final assessment: Breakout EDU
Elements
Puzzles, hidden message pills, boxes, and padlocks, QR codes, wooden polyhedra, scissors, crossword, encryption wheel, Thanos gauntlet and infinity gems, invisible ink, UV torch, Classcraft platform scoring, final prize, and individual diplomas. The event also included: video games application and quiz questions; a poster exhibition of women scientists and mathematicians; model of the layers of the earth's crust; an augmented reality application; smartphones; NeoTrie VR and virtual reality glasses with controllers; countdown timer.
Mechanism
An educational Breakout is a gamification activity in which students must overcome challenges or missions to open a series of padlocks or a closed box. It is an immersive game similar to an Escape Room, but educational in nature. The project's main objective is for students to experience an adventure and solve a problem. The duration to reach the final prize is one hour.
Dynamics
The central narrative theme of the Breakout EDU was based on the students' preferences. The theme chosen was the "Avengers". Each student had already been assigned their role through the Classcraft platform and had interacted with their avatar throughout the sessions. The video presentation sent out by the "Avengers" asked for their help in overcoming a series of STEM focused tests and challenges to find the infinity gems, place them in Thanos' gauntlet, and help save humanity. The first thing each team found was a puzzle card that they had to solve to read the first message. This message led them to a "pill or quark" hidden in one of the layers of the earth's crust (models made by them in the geology course). Inside the quark was a hidden message with coordinates to find a box. Box 1 contained a QR code that took them to a mobile video game that they had previously created in Session 5, with questions on the topic of geometric bodies, and by answering these questions correctly they obtained the key to the first lock for Box 1. Box 1 contained a blank piece of paper, a word search or crossword puzzle, scissors, QR codes, and an encryption wheel (Figure 13). Following a series of challenges provided through QR, solving names of Archimedean solids and questions related to polyhedra that appear in nature in the form of Archimedean solids and platonic solids (polyhedric viruses, polyhedric minerals), the team obtained the clue to the location of the ultraviolet torch. The torch would help them to see what was written on the blank paper with invisible ink. It revealed a figure of the polyhedron dual drawn on the paper and visible to the naked eye, which led to the next clue (Figure 14). The clue was a word created by crossing the lines of the crossword puzzle. This word was the name of a polyhedron in augmented reality visible through a QR code (Figure 15). Cutting out the cipher circle and matching the letters of that name with numbers would be the combination for the lock that opened Box 2. The clue inside Box 2 led to panels displayed in the Institute of Women Scientists to find out about the first woman mathematician who taught polyhedra with manipulative materials (Grace Chilshom Young). Hidden with the text was the number combination to open the penultimate box, Box 3. Inside Box 3 was a plastic figure of a regular polyhedron, of which they had to figure out its axes of rotation with virtual reality, or simply by signing in the air as some of the team members did (Figure 16). Once figured out, if the number of axes of rotation were correct, it would reveal the number to open the last lock on the box. This number was the same for the whole class. This last lock could not be opened without the help of the remaining teams and their numbers obtained from axes of rotation of each figure. Inside the last box was the gauntlet of Thanos, to which they were to attach the gems each team had found, along with the wooden polyhedron. One student was to put it on and give the snap when the whole class was present and gathered around it. Thus, they received their prize, which was nothing material but the satisfaction of having achieved it with enthusiasm and joy, which could denote intrinsic motivation.

Source: own elaboration.

Some images of the sessions are shown below.

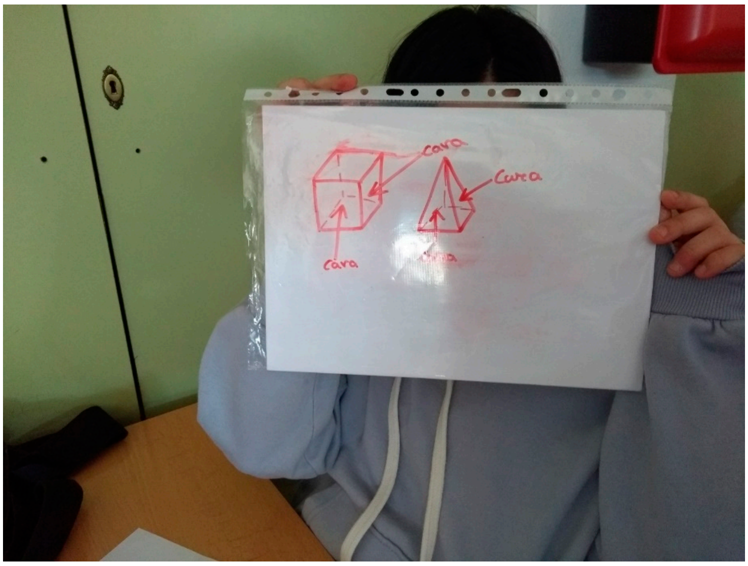


Figure 6. Student's answer in "Miniboard" drawing faces of polyhedral in initial assessment.

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

Figure 7. (**a**) wooden geometric bodies; (**b**) student classifying geometric bodies.

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

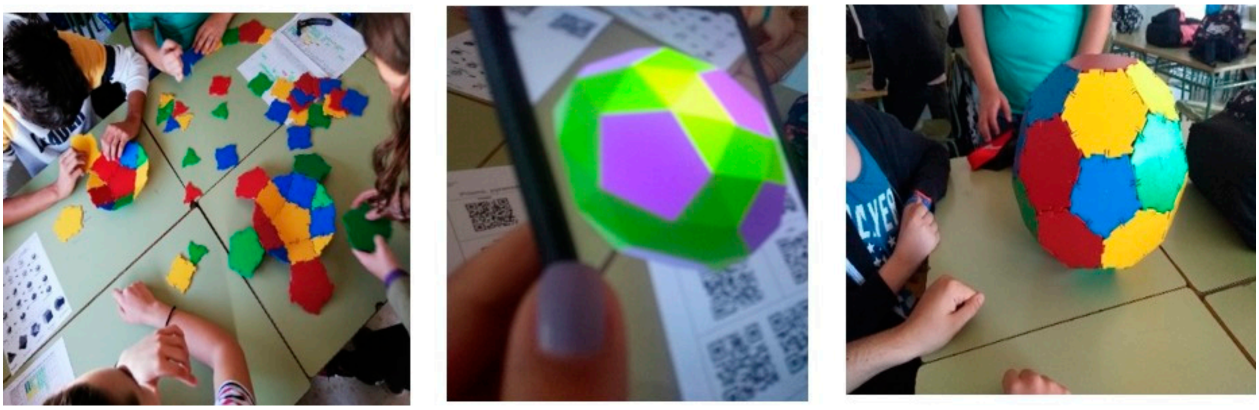
Figure 8. (**a**) student's research works (origami, 3D draws); (**b**) student's research work (video game quiz in Genially).

Figure 9. Polyhedral game "who's who". Own elaboration.

Figure 10. Students playing with one of the polyhedral games designed by them.

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

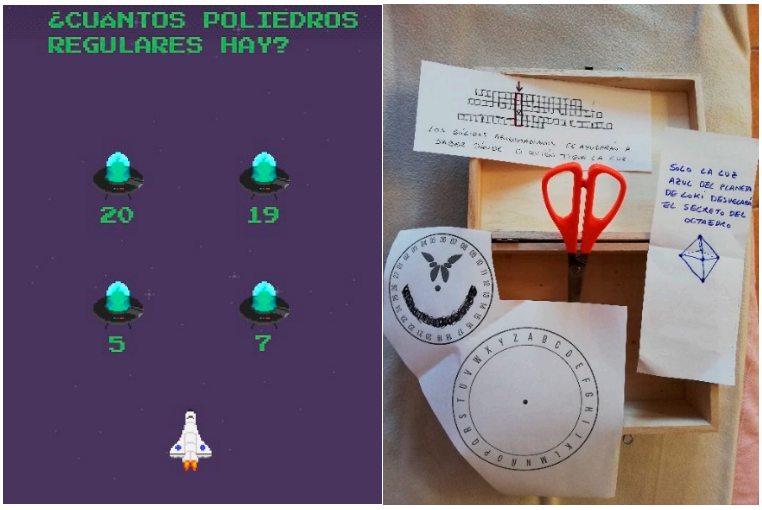
Figure 11. (**a**) student doing planes of symmetry with NeoTrie VR; (**b**) student doing planes of symmetry with manipulative materials; (**c**) dual solid hexahedron-octahedron made with NeoTrie VR by students.



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

Figure 12. (**a**) students doing truncated polyhedra with polydron game; (**b**) truncated icosahedron with AR; (**c**) truncated icosahedron with polydron game.

Some images of Breakout EDU from session 12 are shown below.



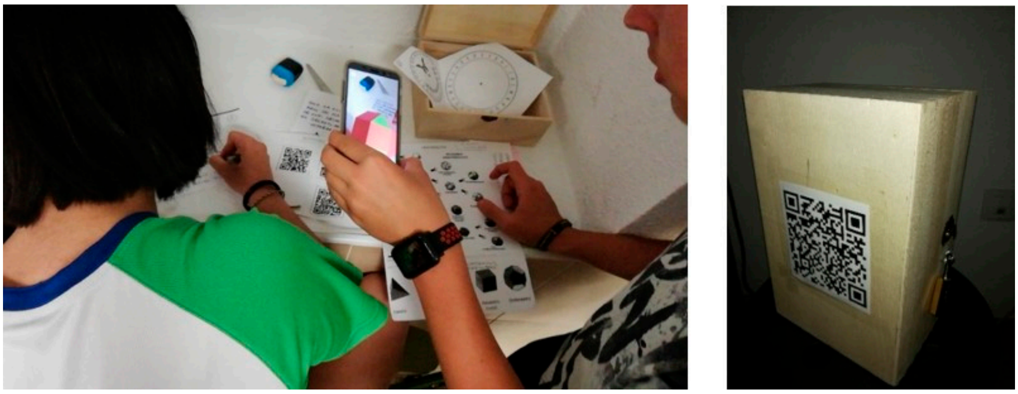
(**a**) (**b**)

Figure 13. (**a**) capture of videogame quiz in Genially; (**b**) elements for Breakout EDU.

Once the development of the didactic proposal for the 12 sessions with the gamified STEM model has been completed, we move on to the evaluation and reflection of the results obtained in this last cycle of the action research. The improvements produced are assessed, observing the learning achieved and participation. This analysis is presented in detail in the analysis and results section below and would form the basis of a new action research cycle in a future course.

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

Figure 14. (**a**) students solving challenges in Breakout EDU; (**b**) clue with dual solid with invisible ink.



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

Figure 15. (**a**) students solving challenges with smartphones; (**b**) clue with QR code in Box 2.

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

Figure 16. (**a**) polyhedron with infinity gem in box 3; (**b**) student doing axels of rotation with software NeoTrie VR.

3. Analysis and Results

This section first analyses the context of the experience of the second cycle of action research with the Classcraft platform and some of the sessions and challenges proposed. The first cycle [90] is not analysed in depth, as the purpose is only to compare it with the second cycle where the gamified STEM experience takes place. Analysis is followed by comparing the scores obtained on the digital educational platforms Edmodo (first cycle) and Classcraft (second cycle). Next, statistics data from the Kahoot! game played in Session 11 of the second cycle are showed. A comparison of the two final assessment sessions of both cycles is also carried out, followed by a subsequent analysis of the student questionnaire at the end of the second cycle using SPSS. There is also a small analysis and quantification of the students' comments in Classcraft's chat and in the teacher's diary. Finally, considering all the results mentioned above, a comparative analysis of the two cycles is made based on several categories and their associated variables.

3.1. Analysis of the Context of the Experience

In the experience, carried out in the second cycle of action research, the students worked in six cooperative learning groups. Group 1 consisted of the two cooperative learning groups working as described above with virtual reality in the sessions where it was necessary to divide the work. Group 2 comprised the other four cooperative learning groups that worked with the manipulative materials. The students chose the names of the six groups: "the Revoliedrons", "Manolo and the Archimedean Mathematicians", "the Eulerians", "the Platonic Unbeatable", "the Hexahedrons" and "the Polyhedrons". Each group, on the Classcraft educational platform, created their corporate group design with the aesthetics of their flags, avatars, virtual mascots and other gamification elements (Figure 17).

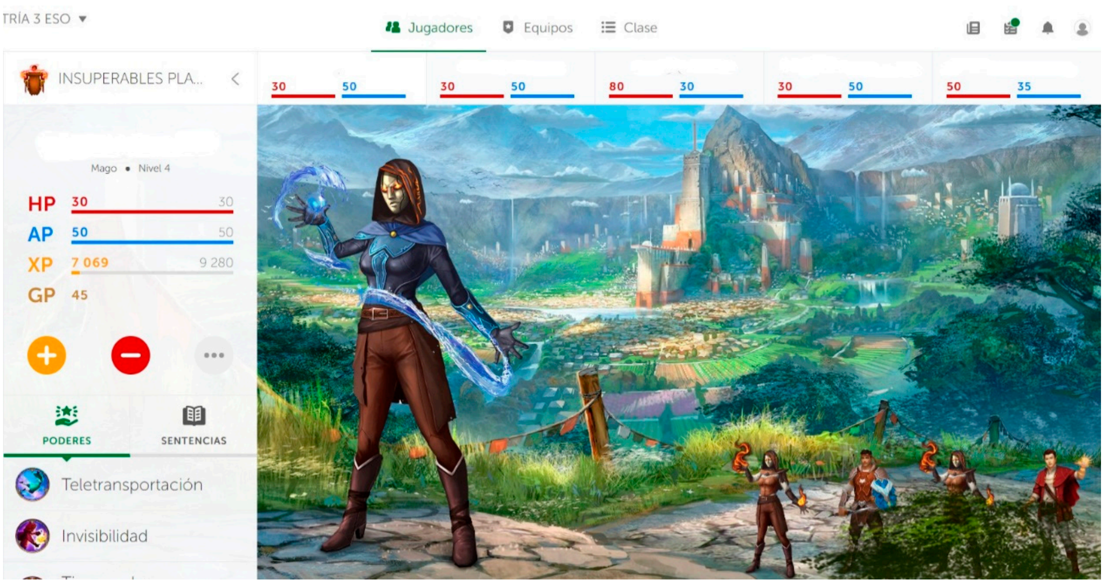


Figure 17. Aesthetics of equipment, avatars, and virtual mascots in Classcraft.

Each student earned points, awarded by the teacher according to work done, for a series of powers they could use, and interact with their classmates through their avatars.

Some of the data obtained during Session 5, where the research work on polyhedra was carried out, included the students' presentation of 14 origami, seven of which were regular polyhedra and seven irregular polyhedra, six three-dimensional drawings, six video games with quiz questions and six videos on nature, art, science and human constructions with polyhedra.

In addition, the Twitter social network yielded the following data after the second challenge: 102 tweets were generated about polyhedral (Figure 18), some of which are shown in the figure, generating more than 300 likes and retweets.

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

Figure 18. (**a**) Tweet with a dodecahedron key ring; (**b**) Tweet with dodecahedron shape playground.

In the fifth challenge, each team created videos (six in total) for each team to be used at the beginning as a trigger for the Breakout EDU. The winning video was uploaded to the platform (Figure 19) so that all could see it before starting the assessment Session 12.

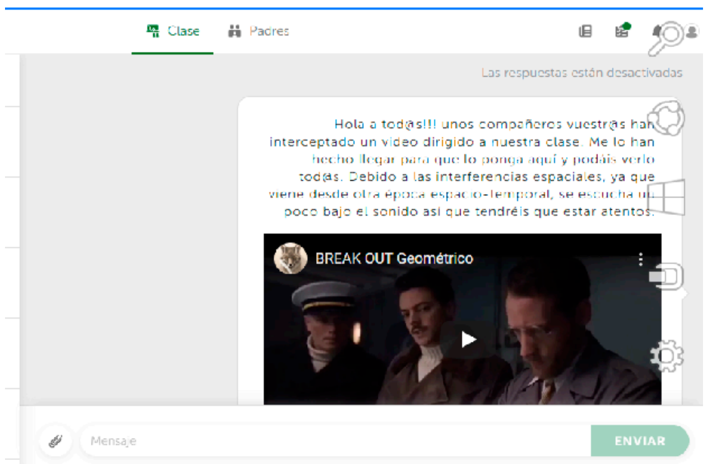


Figure 19. Winning video to kick off the Breakout EDU is showed in Classcraft's chat.

In this second cycle, students used the platform in all the sessions and interacted with the possibilities offered by the gamification elements. The scoring system was displayed to each student individually and as a group, in teams (Figure 20).

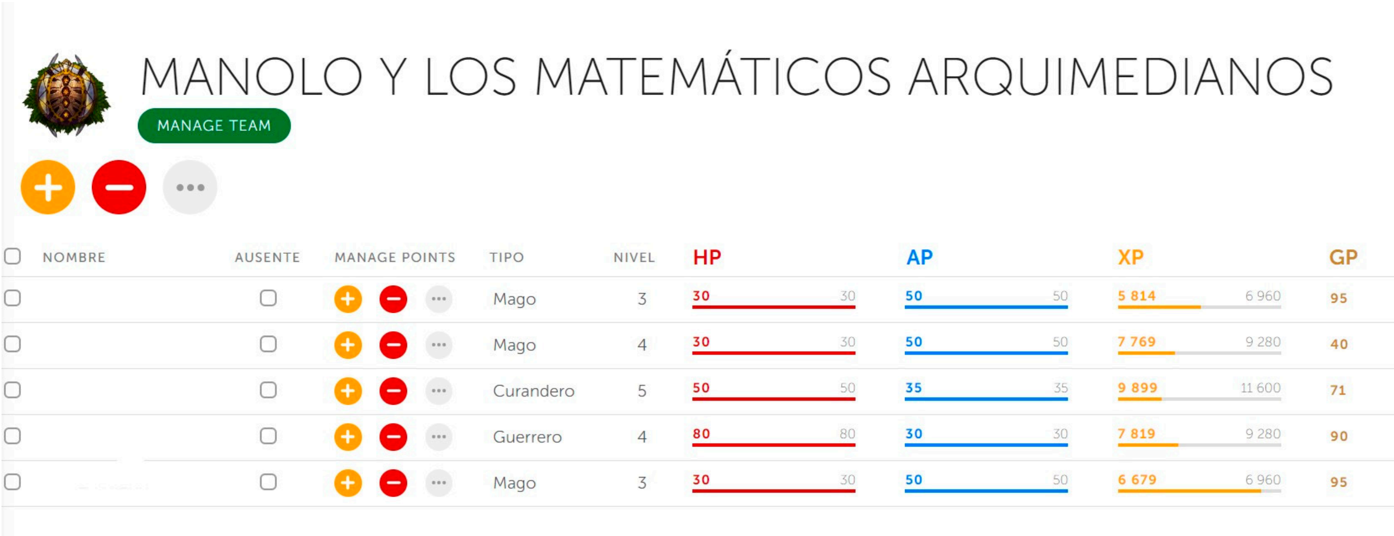


Figure 20. Team score data or leader board in Classcraft.

In addition, at the end of the experience, each student was given a personalised diploma highlighting their skills, empathy, and cooperation during the sessions.

The following are qualitative and quantitative results derived from the data provided by the analytical tools.

3.2. Comparison of Final Scores between Edmodo and Classcraft

The following graph shows the final scores obtained in each action research cycle. As we can see in Figure 21, the orange lines give the score results of the 28 students who took part in the first action research cycle, where the Edmodo platform was used. The blue lines show the scores of each of the 30 students in the second action research cycle using the Classcraft platform.

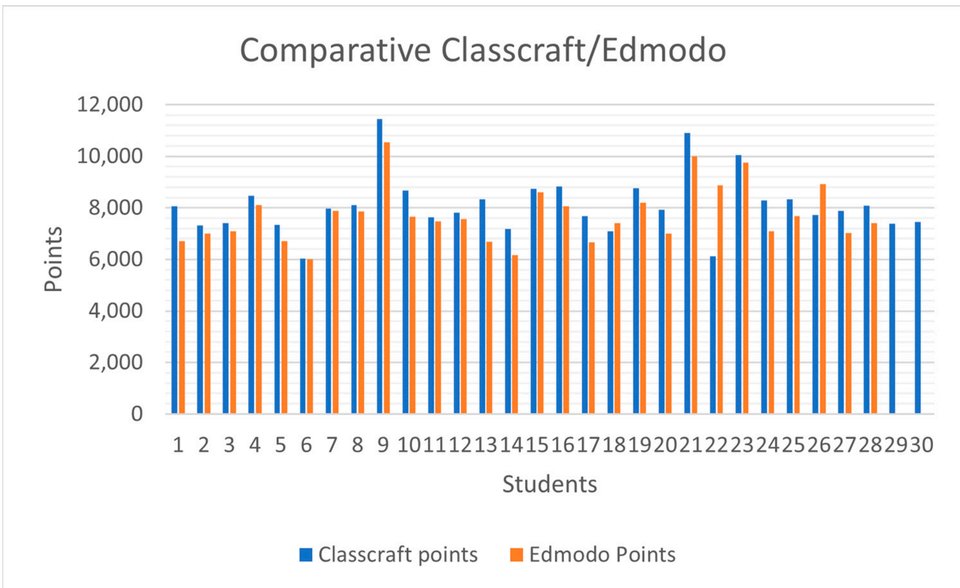


Figure 21. Comparison of points obtained in Edmodo and Classcraft by students.

As can be seen in Figure 21, most pupils scored higher in Classcraft than in Edmodo, although for Pupil 6, the scores were equal, while the scores in the first cycle were higher than in the second for Pupil 22. In contrast, Pupils 29 and 30 have no Edmodo scores as they joined in the second action research cycle and did not participate in the first cycle. All scores are above the 6000-point threshold.

Figure 22 shows how the minimum value in both educational platforms are above 6000 points. Both boxplots show outlier variations, the dispersion in the two platforms is similar, although Classcraft (second action research cycle) shows a higher maximum outlier variations than Edmodo (first action research cycle). The average variation of Edmodo is slightly below that of Classcaft.

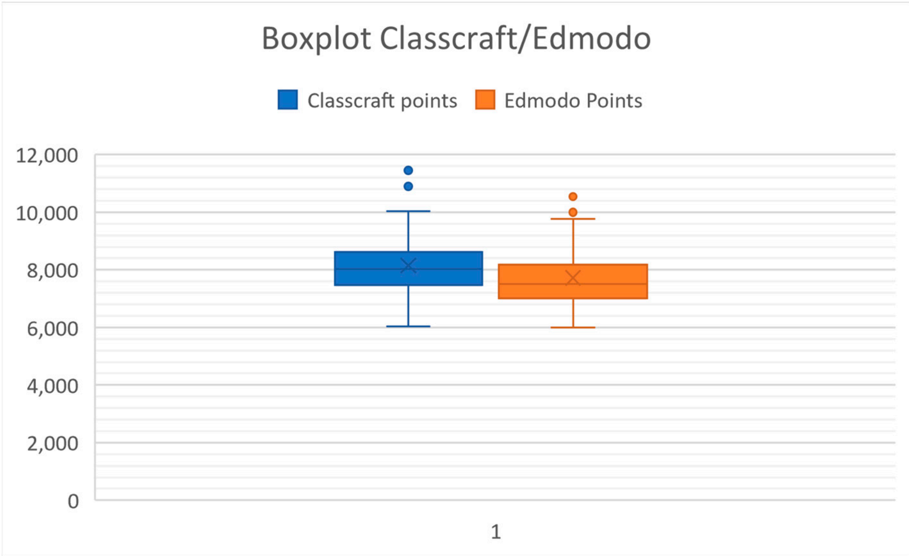


Figure 22. Boxplot obtained with points in Edmodo and Classcraft by students.

3.3. Data Obtained from Kahoot!

In the Kahoot! review game, which took place in Session 11, 20 questions were answered (Appendix B). To participate in the game, the students answered individually or in pairs. In the end, 12 pairs were formed, and 6 students answered individually. The data representing the number of correct answers is shown in the following graph.

As can be seen in Figure 23, there are not any students, individually or in pairs, who got less than five correct answers, the worst result was seven correct answers, as shown in Table 4, where the data is ordered according to the correct answers and the students' positions, from 1 (the winner), to 18 (last place). Moreover, Figure 23 shows that most students are in the range of 10 to 15 correct answers. On the other hand, only 4 students or pairs of students got more than 15 correct answers; the student with the most correct answers got 19 out of 20 questions correct. As can be seen in Table 4, the students who answered individually were in positions 1, 3, 4, 16, and 18. The remaining positions corresponded to the students who participated in pairs.

Table 4. Student's final position in Kahoot! with correct answers.

Final Position in Kahoot!	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Number of correct answers	19	18	17	17	15	15	14	14	14	13	13	12	12	12	10	10	8	7

Source: own elaboration.

In addition, at the end of the game, this application provides some data concerning the right and wrong answers. Thus, 78% of the participants got more than half of the questions right. A total of 11% got just over half correct, and only the other 11% fell below that threshold, getting eight and seven questions correct, respectively. Questions 14, 17, and 20, had the lowest percentage of correct answers, with only 33% of students answering correctly, perhaps because questions 17 and 20 involved arithmetic calculations. However, questions 8, 15, and 16, related to truncated polyhedra and their names, which a priori could be assumed to be a source of error and difficulty in geometry, exceeded 80% of correct answers. Questions 12 and 13 related to axes of rotation, and also had favourable percentages of correct answers with 89% and 83%, respectively.

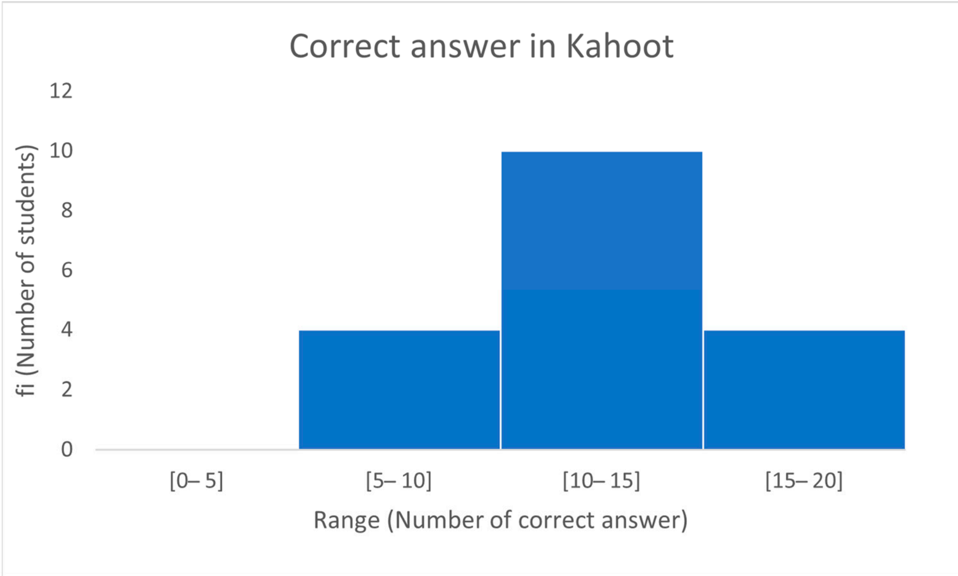


Figure 23. Correct answers in Kahoot! for each student or pair of students.

3.4. Comparison of Final Assessment Sessions of the Two Action Research Cycles

As previously explained, the final assessment used differed in both action research cycles. In the first cycle, it was a Gymkhana (team competition) and a Breakout EDU in the second action research cycle. The following table (Table 5) compares the assessment carried out in both action research cycles.

Table 5. Comparative final evaluation of first and second action research cycle.

Variables	Cycle 1 Gymkhana	Cycle 2 Breakout EDU
Working system	Collaborative teams	Cooperative learning teams
ICT	Virtual maps, smartphones	Smartphones, augmented reality, virtual reality and 3D glasses, video game apps with quizzes, QR codes.
Manipulative Elements	Paper, tape measure	Paper, geometric shapes, invisible ink, ultraviolet light, boxes, padlocks, message pills, Thanos' gauntlet, and infinity gems.
Mechanism	Tracks via smartphone and on paper	Clues and challenges through initial video, QR, augmented reality, paper (crossword puzzle, message), apps, panels of women mathematics and scientists, and virtual reality.
Dynamics	Repetitive same tools	Non-repetitive and always with different tools and elements.
STEM content	Inaccessible heights with mirrors and technology	Technology, polyhedra in nature, art and science, and human constructions, layers of the earth's crust, atoms, geology, etc.

Source: own elaboration.

As the Table 5 shows, the Breakout EDU used as a tool in the second action research cycle for the final assessment is much more comprehensive. This is reflected in the elements used in both ICT and the manipulative materials. In addition, in the second cycle, the student must collaborate more with the rest of the class to solve the proposed challenges. In addition, the mechanics and dynamics are more varied and more focused on STEM, touching on all the content seen during the sessions.

3.5. Analysis of the Final Questionnaire on the Second Action Research Cycle

As explained above and as seen in Appendix A, this questionnaire consists of 12 items, or questions, structured in 4 levels on the Likert scale. Students could decide how they wanted to answer, thus avoiding the intermediate level. This questionnaire has been analysed quantitatively using SPSS.

The reliability obtained yields a Cronbach's Alpha of 0.724.

Confirmatory factor analysis is then carried out to group the items into factors. To see if this is possible, we used the descriptive KMO statistic (Kaiser-Meyer-Olkin's measure of sampling adequacy), which tests whether the partial correlations between variables are small, and Bartlett's test of sphericity. The KMO value was 0.730, so we performed a confirmatory factor analysis with the extraction method: principal component analysis, rotation method: Varimax with Kaiser normalisation. In the rotated component matrix, the rotation has converged in 12 iterations. The correspondence with the different groups is indicated by pointing out the value of each item greater than +0.5 o −0.5 (Table 6).

Table 6. Confirmatory factor analysis of clustering questionnaire results.

Factor 1
1. Using my mobile phone in class helps me learn (0.605)
2. I like to learn more through games than through textbook activities (0.890)
7. VR activities are easy for me (0.887)
8. I can count the order of the axes of rotation better when I see it in Virtual Reality than with the textbook (0.898)
9. It is easy to make symmetry planes. I would be able to make them right now with VR (0.639)
10. VR helps me visualise objects I didn't understand before (0.598)
Factor 2
3. I learn better by working as a team with my colleagues than on my own (0.941)
11. The way I work these days makes it easier for me to communicate with my colleagues (0.598)
Factor 3
4. The class flies by when I work with maths games (0.645)
5. I learn more when I have fun and participate more actively (0.628)
Factor 4
6. Over the last few days, I was able to confirm whether what I was doing was right or wrong (0.547)
12. I have acknowledged my failures (0.514)

Source: own elaboration.

This analysis results in a clustering into four factors. The sedimentation plot confirms this dimensional clustering. Therefore, the grouping of the 12 items of the questionnaire would be as follows.

Based on the groupings, it can be seen that Factor 1 and Factor 4 are related to academic performance, in this case, the former to ICT enhanced learning and the latter to assessment. Factor 2 deals with group cohesion, cooperation, and participation, and Factor 3 focuses on motivation.

In addition, these 12 questionnaire items yield the following statistical values, shown in Table 7.

Table 7. Statistical values of the 12 questionnaire items.

ITEM	1	2	3	4	5	6	7	8	9	10	11	12
Media	3.36	3.73	3.50	3.76	3.80	3.43	3.26	3.73	3.50	3.46	3.56	3.43
Deviation	0.69	0.52	0.77	0.43	0.40	0.62	0.58	0.44	0.77	0.57	0.56	0.50
Variance	0.47	0.27	0.60	0.18	0.16	0.39	0.34	0.20	0.60	0.32	0.32	0.25

Source: own elaboration.

As can be seen from these results, almost all averages are high, close to the maximum value of 4. We see that the dispersion values in the questionnaire are less than one with a maximum deviation value of 0.77, indicating a compact sample.

The results of the questionnaire answers of the 30 students are shown below in Table 8.

Table 8. Questionnaire results.

Statements	1. Strongly Disagree	2. Disagree	3. Agree	4. Strongly Agree
1. Using my mobile phone in class helps me learn	0%	7%	50%	43%
2. I like to learn more through games than through textbook activities	0%	3%	20%	77%
3. I learn better by working as a team with my colleagues than on my own	3%	7%	27%	63%
4. The class flies by when I work with maths games	0%	0%	20%	80%
5. I learn more when I have fun and participate more actively	0%	0%	20%	80%
6. Over the last few days, I was able to confirm whether what I was doing was right or wrong	0%	7%	43%	50%
7. VR activities are easy for me	0%	7%	60%	33%
8. I can count the order of the axes of rotation better when I see it in Virtual Reality than with the textbook	0%	0%	20%	80%
9. It is easy to make symmetry planes. I would be able to make them right now with VR	3%	7%	27%	63%
10. VR helps me visualise objects I didn't understand before	0%	3%	47%	50%
11. The way I work these days makes it easier for me to communicate with my colleagues	0%	3%	37%	60%
12. I have acknowledged my failures	0%	0%	57%	43%

Source: own elaboration.

Tables 6 and 8 are analysed together according to the results and the grouping into factors. Relating to questions that are grouped into Factor 1 and Factor 4 corresponding to academic performance, in relation to ICT-supported learning, question 1, which refers to m-learning, shows that 43% of students strongly agree and 50% of students agree that the use of mobile learning in the classroom helps them to learn. Questions 7–10, which encompass spatial skills in geometry related to VR, also show positive results. Specifically, in question 8, 80% of the students strongly agree and the remaining 20% agree that with the three-dimensional VR tool, it is much easier to count the axes of rotation than when they count them in the textbook. Furthermore, in question 9, only 3% of the students strongly disagreed to make the symmetry planes of any regular polyhedron with the VR tool. In question 10, 50% of the students strongly agree and 47% agree that the VR tool helps to improve the visualisation and space skills of objects. Finally, in question 7, only 7% think that doing the activities with the VR tool is difficult. Factor 4 is more oriented towards assessment within academic performance. In question 6, only 7% of the students cannot identify, in the sessions, whether what they have been doing was right or wrong. In question 12, 43% of the students strongly agree and 57% agree that they have acknowledged their failures in the activities.

Factor 2 deals with group cohesion, cooperation, and participation. In question 3, 63% of students strongly agree and 27% agree that they learn better by working as a team with colleagues, than by themselves. In the same sense, in question 11, only 3% disagreed that the methodology followed during the didactic sequence made it difficult for them to communicate with classmates. Finally, concerning Factor 3 focusing on motivation, in question 4, 80% of students strongly agree and 20% agree that the class flies by when they work with maths games, and the same results in question 5 ensured that students learn more when they have fun and participate more actively.

3.6. Analysis of the Cycle Student's Comments from Classcraft's Chat and Teacher's Diary

After the sessions, the students interacted with the Classcraft educational platform, and made comments in the chat. There are 319 comments (see [89] for more details). Moreover, during the sessions, when the students were doing the individual or group activities, or when the session was finished, they made comments on what and how they worked that day; these comments were collected in the teacher's diary and there are a total of 87 comments. In Table 9, these comments are categorized and quantified, and some examples are also shown.

Table 9. Categorisation and quantification of students' comments.

Category	**Indicators**	**Number of Comments**	**e.g.,**
M (Motivation)	Interest in learning Rewards Participation Fun	**Classcraft's chat 54%** **Teacher's diary 45%**	"The classes have flown by, the bell goes off, and I say... are we done already?" "I'm going to miss the classes and making the shapes in virtual reality because you could see everything much better, and then you remember." "I like to work like this in maths classes. It's easier. When will we do it again with another topic?" "Of course, I would repeat this experience. Everything is much clearer."
AP (Academic Performance)	Qualifications STEM Competencies Reasoning	**Classcraft's chat 25%** **Teacher's diary 27%**	"I will always remember the symmetry planes of a cube." "With virtual reality, you see things for real . . . clearer . . . I can imagine what they are like." "I have never seen polyhedrons so close and so real. Now I can see them; before, I didn't understand them. You can even get inside, and it's as if you were doing it yourself, it's easier, and I like it."
E (Emotions)	Satisfaction Tolerance Positive attitude Success	**Classcraft's chat 13%** **Teacher's diary 20%**	"Making polyhedra with virtual reality is easier, and I like it." "I love working with my colleagues like this because if I don't know something, I can ask them, or they can ask me, and we all help each other." "When will we do this again, to learn a maths subject like this?" "I have done all the symmetry planes the first time." "I have come up with a super cool drawing and origami." "I have helped my partner when she has asked me, and we have learned together"
Others	Interaction with ICT Others	**Classcraft's chat 8% Teacher's diary 8%**	Not relevant

Source: own elaboration.

As can be seen in Table 9, most of the comments in the Classcraft's chat and during the sessions were about motivation, followed by those referring to academic performance, and emotions in third place. Finally, there were some comments on the relationship with ICT, but these were few and not relevant.

3.7. Analysis of the Design of the First and Second Action Research Cycles

Once some of the results derived from the data obtained with the analysis instruments have been presented, we then analyse the gamified STEM design of both cycles. Five categories are defined according to [56]. These categories are associated with motivation (M), academic performance (AP), commitment/participation (CP), emotions (E), and group cohesion/cooperation (GC). The main variables associated with each of these categories are presented in Table 10.

Table 10. Categories and variables.

Motivation (M)
M.1. Intrinsic motivation (interest in learning) M.2. Extrinsic motivation (Rewards) M.3. Participation M.4. Interactive platforms M.5. Novelty, fun, discovery
Academic performance (AP)
AP.1. Qualifications AP.2. Acquisition of STEM skills AP.3. Abandonment reduction AP.4. Meaningful learning and reasoning AP.5. Social networking: short-term performance
Commitment/Participation (CP)
CP.1. Facing challenges CP.2. Permanence and engagement with ICT CP.3. Attendance and submission of work CP.4. Persistence after achieving goals, perseverance C.P.5. Common objectives
Emotions (E)
E.1. Tolerance of mistakes E.2. Positive mood E.3. Low level of anxiety E.4. Satisfaction E.5. Group success
Group cohesion/cooperation (GC)
CG.1. Unity, sense of belonging CG.2. Social skills CG.3. Contribution of all members CG.4. Altruism, cooperation, enrichment of approach CG.5. Interaction and communication with ICT

Note: Source [56].

Both cycles are analysed below regarding these categories and their associated factors, pointing to evidence from the analysis tools (Table 11). The results of the research are shown separately, in three different moments: the starting point, Point 0, after the initial observation; the results of Cycle 1 (see [90] for more details), which are analyzed after the first cycle of the action research; and, finally, the results of Cycle 2, after the second cycle.

As seen in the Table 11, comparing both cycles, greatest motivation occurs during the second cycle (results Tables 8 and 9), showing an interest in learning. Participation in the digital educational learning platform, Classcraft, was higher than in Edmodo, due to its gamification features (Figure 22 and [89]). The sessions in the second cycle have been designed to include more active methodologies and the whole gamification process in Classcraft with a STEM approach and ICT. It has contributed to better academic performance (qualifications, results in Kahoot!) and the acquisition of more STEM-related skills (solving Breakout EDU challenges, AR and VR sessions), leading to more meaningful learning, reflected in the reasoning shown by students during the second cycle. The experience has made the students more inclined to face challenges, hand in all the work, and persist in achieving the proposed objectives. They did all this with a feeling of relevance and collaboration with the rest of the group and class (results Tables 8 and 9). In addition, students throughout the second cycle showed tolerance for mistakes during the sessions as observed in the teacher's diary. They attempted things without showing anxiety and were generally in a positive mood (results Table 9). In addition, they showed satisfaction with both their individual and group work (results Tables 8 and 9), thus improving their level of cooperation and social skills.

Table 11. Variables of the categories.

Variables Associated with M	Point 0 Traditional	Cycle 1 Approximate Model to a Gamified Approach to STEM	Cycle 2 Complete Gamified STEM Model
M.1. Intrinsic motivation (interest in learning)	Not applicable	Video research work on geometric proportionality made by students.	Evidence of research work from Session 5 (origami, videos, drawing, etc.) Results in Table 9 (M).
M.2. Extrinsic motivation (Rewards)	Not applicable	Edmodo badges. Points and powers cards.	The entire Classcraft reward system (avatars, virtual mascots, powers, badges, challenges or quests, etc.).
M.3.Participation	Traditional master class. Passive students.	12 sessions (2 master class and 10 practical). More active students.	12 practical sessions. Active students. Virtual interactions on the Classcraft platform. Results in Kahoot!
M.4. Interactive platforms	Not applicable	Edmodo (homework and badge delivery).	Classcraft with a fully gamified system.
M.5. Novelty, fun, discovery	Not applicable	Games-based learning (GBL), challenge-based learning (CBL).	Game-based learning (GBL), challenge-based learning (CBL), narrative, simulators VR (NeoTrie VR), AR, apps, social media (Twitter), full STEM gamification.
Variables Associated with AP	**Point 0 Traditional**	**Cycle 1 Approximate Model to a Gamified Approach to STEM**	**Cycle 2 Complete Gamified STEM Model**
AP.1. Qualifications	2 "A Grades" (outstanding), 1 "B Grade" (very good), 10 pass grades, 15 fails grades.	8 "A Grades" (outstanding), 13 "B Grade" (very good), 7 pass grades. (Edmodo data points).	15 "A Grades" (outstanding), 13 "B Grade" (very good), 2 pass grades. (Classcraft data points).

Table 11. *Cont.*

Variables Associated with AP		Point 0 Traditional	Cycle 1 Approximate Model to a Gamified Approach to STEM	Cycle 2 Complete Gamified STEM Model
AP.2. Acquisition of competences STEM	**S (Science)**	Not applicable	Reflection and refraction rays are used to measure inaccessible heights through a mirror in an escape room. Geography in Gymkhana.	Geology (e.g., layers of the earth's crust in Breakout EDU). Elements of nature related to polyhedral shapes (viruses, atoms, minerals, etc. in activities).
	T (Technology)	Not applicable	Use of interactive maps and mobile apps	Use of mobile apps (creation of quiz-type video games in session 5). NeoTrie VR for the development of spatial visualisation skills (sessions 8, 10,11). Social networks (Twitter in second challenge). Use of augmented reality with QR codes (session 9). Participation in the virtual world of Classcraft.
	E (Engineering)	Not applicable	Construction of models of the classroom tables using scales.	Construction of polyhedra through origami, with and without face structure with paper and with games such as Zome and Polydron. Construction of polyhedra in NeoTrie VR.
	M (Mathematics)	Mathematics with blackboard and notebook	Mathematics (geometry) with mixed method: blackboard and notebook, introduction to active methodologies.	Mathematics (geometry) with active STEM methodologies gamified with Classcraft.
AP.3. Abandonment reduction	Passive, bored pupils in the classroom. Absenteeism.		Active pupils, participation in the classroom. No absenteeism.	Active students, participation in the classroom and outside the classroom on the platform. No absenteeism.
AP.4. Meaningful learning and reasoning	Not applicable		Demonstration of the Pythagorean theorem with puzzles. Self-initiated calculation of inaccessible height with indirect methods as the day was cloudy and could not be done with shadows.	Deduction of the existence of only five Platonic solids, induction of Euler's theorem, solving all the trials in the final assessment Breakout EDU. Statistical data results of hits from Kahoot! Results Table 9 (AP).
AP.5. Social networking: short-term performance	Not applicable		Not applicable	Using Twitter to develop spatial visualisation skills with a photo contest (number tweets, retweets, likes).

Table 11. *Cont.*

Variables Associated with CP	Point 0 Traditional	Cycle 1 Approximate Model to a Gamified Approach to STEM	Cycle 2 Complete Gamified STEM Model
CP.1. Facing challenges	Not applicable	Sporadic offline challenge.	Table 2 of weekly challenges and sessions.
CP.2. Permanence and engagement with ICT	Not applicable	Not applicable	Extra NeoTrie VR sessions during break times. Twitter activity.
CP.3. Attendance and delivery of work	Homework, often without feedback	Delivery in Edmodo or externally on platform.	Integrated Classcraft platform delivery, daily interaction with powers and avatars. Delivery of challenges and work in the sessions.
CP.4. Persistence after achieving goals, perseverance	Not applicable	Not applicable	Construction of Archimedean polyhedra (football—truncated icosahedron) at the end of the class. When the next group came in, nobody moved until they had finished building it. They didn't want to leave.
C.P.5. Common objectives	Not applicable	Gymkhana for each group	Breakout EDU could not be resolved without the participation of all groups. Teams in Classcraft and the interaction between them and their components. Results Table 8. Results in Kahoot!
Variables Associated with E	**Point 0 Traditional**	**Cycle 1 Approximate Model to a Gamified Approach to STEM**	**Cycle 2 Complete Gamified STEM Model**
E.1. Tolerance for mistakes	Not applicable	Pythagorean puzzles attempted to the level reached by each team.	All sessions (e.g., attempting to create the polyhedra repeatedly with the construction games until they came out, giving wrong answers in the games but still participating and improving).
E.2. Positive mood	Not applicable	They expressed enthusiasm for the methodological change proposed and showed interest in continuing the experience.	At the end of the Breakout EDU, the whole class applauded and hugged each other as a group, having managed to finish the task before the one-hour time limit. The mood was very positive throughout the whole experience. Results Table 9 (E).

Table 11. *Cont.*

Variables Associated with E	Point 0 Traditional	Cycle 1 Approximate Model to a Gamified Approach to STEM	Cycle 2 Complete Gamified STEM Model
E.3. Low level of anxiety	High level of anxiety (comments from students such as: "I can't wait for this to be over, let's see if I pass maths.") "I'm getting desperate because I don't know anything." "I don't want to be put on the board because I don't know how to do it." "I'm bored.")	Medium level of anxiety (comments from students such as: "I'm nervous about the exam." "What do I have to do to pass maths? We're not doing exams.")	There is hardly any anxiety. (There were no comments about not wanting to participate or go out in any of the sessions, or about the exam or being nervous about not knowing how to do something. Anxiety was only rarely expressed when they did not have time to finish building the geometric bodies. There was no penalty for an incompletion, only their desire to finish building it.)
E.4. Satisfaction	Not applicable	Comments from students of satisfaction at the end of the course by the students: "I am happy with my work on this topic." "I've managed to do everything you sent me. It's been a long time since I've done that in maths."	Results Table 8. Results in Kahoot! Results Table 9 (E).
E.5. Group success	Not applicable	Inaccessible heights calculated in the courtyard, Pythagorean puzzles, Gymkhana	All sessions were cooperative and group-based, including the Breakout EDU final assessment.
Variables Associated with CG	**Point 0 Traditional**	**Cycle 1 Approximate Model to a Gamified Approach to STEM**	**Cycle 2 Complete Gamified STEM Model**
CG.1. Unity, sense of belonging	Not applicable	Individual or collaborative work.	Cooperation when playing Kahoot! Cooperative learning work, Classcraft group membership with coats of arms and design of corporate identity.
CG.2. Social skills	Not applicable	Some in the Gymkhana or measured inaccessible heights courtyard.	Twitter, Classscraft, in class exercising with their cooperative learning roles.
CG.3. Contribution of all members	Individual work	Only in some sessions.	All sessions.
CG.4. Altruism, cooperation, enrichment of approach	Not applicable	Only in Gymkhana.	All sessions.
CG.5. Interaction and communication with ICT	Not applicable	Edmodo, interactive maps, QR codes with smartphones.	Classcraft, Twitter, AR, VR, QR codes, quiz video games apps, Kahoot!

Source: own elaboration.

4. Discussion and Conclusions

The study allowed answering research questions. Regarding RQ1, the academic performance improves when using a gamified STEM design supported by the Classcraft platform, as can be seen from the results. In Figure 22, Classcraft shows higher maximum outlier variations than Edmodo. Table 11 (AP.1) shows improvement in qualifications and, moreover, Table 11 (qualitative results AP.2–AP.5) shows improvement in academic performance's variables. In addition, Figure 23 shows the high number of correct answers in the Kahoot! assessment activity. Moreover, results in Table 8 (Questions 1,2,7,8,9,10, 6, and 12 results agree percentages), where most students with a high percentage claim to have learnt the concepts covered, and finally, the results in Table 9, where comments on academic performance are in second place overall. If we compare the results obtained in similar studies mentioned by [50], this confirms that the STEM model supported by gamification improves academic performance, specifically in geometry, providing a more functional view of mathematics, as indicated by [2]. The sessions designed under this model utilizing the structure proposed by [24] facilitate much better use of class time supported by the educational platform, and the more practical activities carried out. In geometry, this leads to, among others, better development of spatial and visual skills (spatial memory, visual discrimination, etc.), coordination, knowledge and analysis of the environment, and creativity. Acquiring these skills, as concluded by [12], leads to improved academic performance and learning from mistakes, as demonstrated by [10] in his study.

In the same sense, other studies [65,66], where a pre-test and a post-test are carried out to see the academic results, the improvement is seen in the activities that have been gamified, comparing with those that maintain their traditional methodology, in which academic performance is maintained or even worsens, corroborating the benefits of active methodologies [20].

Regarding RQ2, the results obtained in this study have confirmed the potential of the literature on the use of active methodologies (serious game as part of gamification) and ICT such as AR or VR in motivation [7,60,89]. Moreover, in Table 8 (Questions 4,5 results agree percentages) shows high percentages of motivation in students. In addition, Table 9 offers most students' comments referring to this variable. The participation on Twitter was very high, with 102 tweets and 300 retweets and likes. During the second action research cycle of the 30 students in the 12 sessions, there were only two absences for medical reasons, which shows a lack of absenteeism due to the gamified design that produces motivation and, therefore, greater participation in the classes. Finally, Table 11 (qualitative results M1–M5) shows improvement in motivation. The results obtained are similar to studies mentioned by [28] where it is shown how games help to increase motivation and develop special skills, and as in our case has been the development of spatial visualisation skills. In [33] the appearance of extrinsic and intrinsic motivation is demonstrated with the serious game Classcraft, with high values in both motivations and in the development of learning. In addition, according to [52–54], three-quarters of the students were highly motivated in the development of the gamified experience and highly satisfied with the usefulness of the proposed activity in their learning process, offering this experience as a didactic strategy.

Regarding RQ3, the gamified STEM experience with cooperative learning techniques, improve group cohesion, as can be seen in the results. In Table 8 (Questions 3,11 results agree percentages) shows high percentages of group cohesion. Moreover, the qualitative results in Table 11 (CG.1–CG.5) suggest group cohesion and cooperation. In this sense also, Table 2, which compares the cooperative learning roles with Classcraft's roles, offers a high percentage of matches. In addition, the final Breakout EDU assessment could not be solved without the collaboration and cohesion of the whole group, which are enhanced, as we see in Table 5, with the cooperative learning techniques. These results show, and according to [38], that creating a structure of cooperative aspects made didactic experience more successful. In addition, and according to [40], the study demonstrated that cooperative learning in gamified experiences is more effective in group cohesion and more attractive for students. From the point of view of student participation and group cohesion, the interaction between peers and between students and teacher increases, thus improving the classroom atmosphere, the resolution of doubt and group work, as indicated by [19,39–41]. Indeed, the relationships that grow and improve in the virtual environment are reflected in the classroom [89].

Verification of the research questions ensures that the objective of the study is partly met., i.e., this study aims to demonstrate that using the gamified STEM model, supported by educational platforms and ICT to work on geometry in secondary education, improves motivation, academic performance, participation, and the group cohesion of students. With regard to emotions, no research question has been formulated since we consider that, although Table 11 (E.1–E.5) offers qualitative evidence of the results, perhaps the data collected are not enough to confirm or reject it, so it becomes a limitation of the study and is proposed as a future line of research linked to motivation as stated in their research [74,75].

A limitation of this study is that in action research, there may be a loss of objectivity, as the teacher is also a researcher. The profile of external researchers who have also analysed the available evidence more objectively is introduced to overcome this fact. Another limitation stems from the fact that this study covered in large part the subjective perception of users in the evaluation. On the other hand, this research was carried out in a specific context, with a single class group, and we cannot compare it with a control group with a traditional didactic design at the same time. Concerning the tools used, there were only two virtual reality equipments available at that time, so the class group had to be divided. In this way, all the students were able to work at the same time, completing the session with the manipulative materials. Concerning serious game, [62] in their study support the emerging notion that caution should be applied when using gamification approaches in educational contexts, as the data show that students should not be involved with these platforms throughout the school period, but should be alternated with other methods in order not to create addiction or out-of-reality contexts. Moreover, [63] points out that spending many hours outside the home with serious games within educational platforms or virtual reality can be detrimental to students as they already spend enough hours with video games in their free time; study shows that 83% preferred to learn mathematics with non-digital materials or manipulative materials in classroom. According to this study, and although in our study the percentage of positive responses to use digital materials is the opposite, we believe that both should be mixed as we have done in our design to supply e.g., visual skills of polyhedra that could not be done without VR tools [9].

This work aims to propose a novel didactic design sequence with practical implementation of modern digital technologies in STEM education for learning about 3D geometry. This study offers a comparison of two action research cycles where gamified STEM didactic design, with various ICT, has been put into practice. It also offers a comparison of the high percentage of matches between the roles assigned as part of the cooperative learning methodology, and the roles chosen by students in the Classcraft educational platform, providing an overview of how students used this educational platform and its advantages over other less comprehensive platforms, such as Edmodo. In addition, a comparison of the two types of final assessment within gamification, such as a Gymkhana and a Breakout EDU, is offered. The study aimed to demonstrate that using the gamified STEM model, supported by ICT such as AR and VR, manipulative materials, and educational platforms (Classcraft), and others active methodologies such as flipped learning and cooperative learning, could improve the teaching-learning process. Improvements were assessed in terms of factors such as student motivation, academic performance, participation, and group cohesion.

Future lines of this work aim to demonstrate that these results could be extrapolated to other contexts; a third cycle of action research will be carried out with more emphasis on serious games and the specific VR tool NeoTrie VR for the development of visual spatial skills in geometry. We will use some specific game evaluation questionnaires such as the Technology Acceptance Model (TAM) and the Technology-Enhanced Training Effectiveness

Model (TETEM), among other specific research instruments, to evaluate and analyze player satisfaction.

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Institutional Review Board Statement: Ethical review and approval were waived for this study, due to its anonymized nature. The activities were revised and authorized by the respective teachers. The parents were informed before their children participated in the study.

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

Data Availability Statement: Not applicable.

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

Appendix A

Rate these statements according to your degree of agreement or disagreement by ticking the corresponding option.

1.STRONGLY DISAGREE	2. DISAGREE	3. AGREE	4. STRONGLY AGREE

	STATEMENTS	1.	2.	3.	4.
1.	Using my mobile phone in class helps me to learn				
2.	I like to learn more through games than through textbook activities.				
3.	I learn better by working as a team with my colleagues than on my own.				
4.	The class flies by when I work with maths games.				
5.	I learn more when I have fun and participate more actively.				
6.	I was able to confirm over the days whether what I was doing in the activities was right or wrong.				
7.	Virtual Reality activities are easy for me.				
8.	I can count the order of the axes of rotation better when I see it in Virtual Reality than with the textbook.				
9.	It is easy to make symmetry planes. I would be able to make them right now with Virtual Reality.				
10.	Virtual Reality helps me visualise objects I didn't understand before.				
11.	The way I work these days makes it easier to get to know and communicate with my colleagues.				
12.	I have acknowledged my failures				

Figure A1. Questionnaire second action research cycle.

Appendix B

Questions in Kahoot! Game:

1. What are regular polyhedra called?
2. Are Platonic solids truncated, regular, irregular, or semi-regular polyhedra?
3. Which of the following are truncated polyhedra?
4. The dual of a hexahedron is a ...
5. Which scientist-mathematician proposed that an excellent way to learn geometry was to manipulate geometric shapes?
6. The dual of an icosahedron is a ...
7. How many planes of symmetry does a cube have?
8. Which of the following are truncated polyhedra?
9. Which of the following geometric bodies are not bodies of revolution?
10. The dual of an octahedron is an ...
11. C + V = A + 2 What is this Theorem called?
12. What is the order of the axes of rotation of a cube?
13. To make the axes of rotation of a cube, I can draw them ... (Available options: from face to vertex, from face to face, from edge to face, etc.).
14. The dual of a tetrahedron is a...
15. A cuboctahedron has ... (available options: different options between the shape of the polygons that form the faces and the number of faces of each)
16. A truncated icosahedron is formed by ... (available options: different options between the shape of the polygons that form the face and the number of faces of each one).
17. If a polyhedron has six faces and six vertices, how many edges does it have?
18. The polyhedra are classified as ...
19. Semi-regular polyhedra are ...
20. If a polyhedron has 20 faces and 30 edges, how many vertices does it have? Is it regular?

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