Teaching and learning mathematics using digital games in the classroom

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Abstract

The Digital Game-Based Learning (DGBL) approach was adopted, and a didactic sequence based on the digital game Triângulo Resgate (Rescue Triangle) was designed and implemented in a public secondary school course in Argentina to teach the metric relationships of the right triangle. The activities of the students and the teacher in each task of the sequence were described and analyzed. The results indicate that the game promotes the active participation of all students in classes, who use, justify, and apply the similarity of triangles and the metric relationships of the right triangle to new situations they create.

Key words

Digital game-based learning, Mathematics, constructivism, metric relationships of the triangle rectangle, secondary school

Résumé

L'approche d'apprentissage numérique par le jeu est adoptée, et une séquence didactique basée sur le jeu numérique Triângulo Resgate [Triangle Sauvetage] est conçue et mise en œuvre dans un cours d'école secondaire publique en Argentine

pour enseigner les relations métriques du triangle rectangle. L'activité des élèves et de l'enseignant dans chaque tâche de la séquence est décrite et analysée. Les résultats indiquent que le jeu favorise la participation active de tous les élèves en classe, qui utilisent, justifient et appliquent la similitude des triangles et les relations métriques du triangle rectangle aux nouvelles situations qu'ils créent.

Mots-clés

Apprentissage numérique par le jeu, Mathématiques, constructivisme, relations métriques du triangle rectangle, lycée

Cite this article

Otero, M. R., Gazzola, M. P., Castro Filho, J. A., & Gomez, A. S. (2024). Teaching and learning mathematics using digital games in the classroom. *Review of Science, Mathematics and ICT Education*, *18*(2), 69-87. https://doi.org/10.26220/rev.5065

Gaming and mathematics

Playing is an activity that humanity has developed over time. In particular, the field of mathematics has always had a playful and creative dimension. For example, the Pythagoreans conducted various studies on numbers, using the configurations they formed with pebbles. In the Middle Ages, Fibonacci practiced numerical mathematics using Arabic techniques and games as tools. During the same period, Cardano wrote a book on random games, *Liber de ludo aleae* (Cardano, 1663), before Pascal and Fermat developed the mathematical treatment of probability (García Cruz, 2008). At that time, intellectual challenges in the form of games emerged, in which participants solved algebraic equations; even Cardano and Tartaglia participated in these kinds of games (de Guzmán, 1989). In the 17th century, Leibniz promoted intellectual games, and in the 18th century, Euler began graph theory with the well-known problem of the seven bridges of Königsberg. Johann Bernoulli proposed the brachistochrone problem to the most outstanding mathematicians of his time (Hernández Abreu, 2007). Gauss also had a great love for card games and conducted statistical studies on the plays, while Hamilton analyzed the problem of traversing the vertices of a regular dodecahedron without repeating any of them. Other illustrious scientists such as Hilbert, Neumann, and Einstein also showed their interest in mathematical games (de Guzmán, 1989).

Games allow us to create situations of great educational and cognitive value that lead to experimenting, investigating, solving problems, discovering, and reflecting. Currently, playing different kinds of games on portable devices is a daily activity for students. When it comes to educational games, students value this approach as creative and entertaining, and even indirectly, they pay more attention to teaching. Another advantage of these games is that they make learning enjoyable while also helping students face difficulties and overcome challenges that require concentration, self-confidence, and patience-crucial attitudes for higher education and throughout life (Liu et al., 2021).

Game based Learning (GBL)

GBL is a teaching method that incorporates games into the learning process to help students learn, understand, and stay motivated. The most commonly used connotation for games is the popular modern video games, which are used by more than 89% of children and adolescents, for example, in the UK (Ferreira et al., 2016). In the last five years studies demonstrate a significant increase in motivation, attraction and interest of students of all ages in the learning process using the GBL approach (Hussein et al., 2019; Hwa, 2018; Khan et al., 2017). Different kinds of digital games can be used and engaged in a variety of ways to educational practice. According to some studies, the effectiveness of GBL is evident for both primary school students, university students and adults (Sung et al., 2017). The psychological impact of video games on attention increases students' interest in learning (Kiili et al., 2018).

The complexity of GBL and the work required to create quality games makes its integration into teaching-learning difficult. There are studies that show students' refusal to use these resources if they are of poor quality (Marconi et al., 2018; Nousiainen et al., 2018; Park et al., 2019). Other research indicates that teachers do not have the necessary knowledge to apply the GBL approach in the classroom (Lindgren, 2018; Hamari & Nousiainen, 2015; Romero & Proulx, 2016; Roepke & Schroeder, 2019).

Digital games in mathematics teaching-learning

Digital Game-Based Learning (DGBL) is an approach that uses digital games for teaching and learning, which has recently emerged as a research area in education (Byun & Joung, 2018). It is often highlighted that DGBL provides students with entertainment, joy, rules, objectives, results and feedback, feelings of success, challenges, the possibility of solving problems, social interaction, and emotional engagement (Prensky & Thiagarajan, 2007). By enjoying learning and feeling challenged, students increase their self-efficacy and persistence in learning (O'Rourke et al., 2017).

Digital games offer an alternative to traditional forms of teaching, which are focused exclusively on the teacher. They make learning more enjoyable and motivating for students (Es-Sajjade & Paas, 2018; Siew, 2018). DGBL is also associated with 21st-century skills, such as critical thinking, creativity, modelling and problem-solving, collaboration, communication, and digital literacy (Gee, 2005; Williams-Pierce, 2019).

Even considering all these benefits and the fact that mathematics and science teachers positively value games as an educational resource when they respond to surveys

(Gazzola & Otero, 2023a, 2023b; Otero et al., 2023, 2024; Otero et al., 2022; Queiros et al., 2022, 2024), this does not translate into teaching practice. Teachers are often unclear about how to use games in the classroom beyond the mere act of playing. Their difficulties may include a limited understanding of how digital games can be useful in an educational context and problems integrating games into existing curricula (Hsu et al., 2021). Teachers need knowledge about the technological and didactic value of digital games (how to teach specific knowledge) and how to integrate them into teaching. Research is needed on how teachers learn to effectively use digital games in teaching. In this sense, there are no studies in the bibliography aimed at training in-service teachers to teach with digital games.

Mathematics is a key discipline in secondary and higher education as it provides foundational knowledge for other domains such as science, engineering, and technology. However, many students consider mathematics courses to be difficult and full of challenges and risks because they expose learners to the possibility of obtaining low grades. This can lead to intense episodes of stress and anxiety (Roick & Ringeisen, 2018). For this reason, many researchers in mathematics education are interested in Digital Game-Based Learning (DGBL) as an attractive teaching technique for students.

In other works (Gazzola & Otero, 2023a, 2023b), we analyze, through surveys and semi-structured interviews, how teachers teach the content involved in the games and with what resources they do so. The results indicate that the traditional way of teaching mathematics and the epistemological conceptions of teachers are related to the reluctance and difficulties they express in using digital educational resources and games in their classes. Thus, when placed in a teaching situation, teachers express that they would use digital games to teach algebraic and transcendental functions (Otero et al., 2023, 2024), for example, to exercise students after having taught in the usual way.

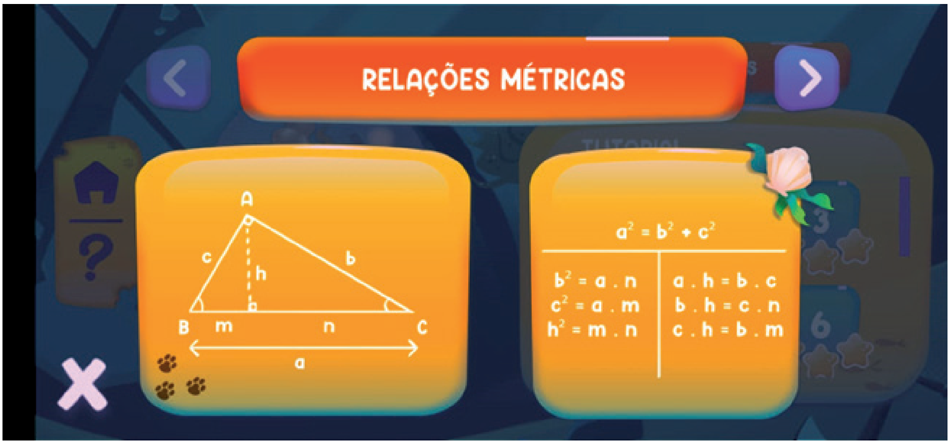
This work aims to describe and analyze the use of the digital game Triângulo Resgate (Rescue Triangle) in the mathematics classroom, both from the perspective of the student and the teacher, adopting a constructivist theoretical framework for teaching and learning. DGBL allows us to develop the potential of digital games in the mathematics classroom in balance with constructivist teaching. In this work, this balance is sought through the design of a didactic sequence to teach the metric relationships of the triangle with the digital game Triângulo Resgate, created by the V-Lab-UFPE team from Brazil (Gomes et al., 2022). This group developed more than fifty free digital games on mathematics and science that run on mobile phones and can be used with or without the Internet. Each of them is accompanied by a teaching guide for the teacher and links to numerous digital resources, constituting a Digital Educational Resource (DER). The DERs were designed according to the criteria of the Common National Curriculum Base (BNCC) of Brazil and were evaluated regarding playability, applicability, user experience, and design and visual representation (Queiros et al., 2022, 2024). They are currently being used and tested in mathematics and science classrooms in school institutions in Brazil and Argentina.

Triângulo Resgate (Rescue Triangle) is a digital game designed to help students/players learn the metric relationships of a triangle rectangle, trigonometric ratios, and the sine and cosine theorems. In this paper, we present a preliminary version of a didactic sequence on the metric relationships of the triangle using the mentioned game. We describe some partial results of a pilot implementation in a public school in Argentina, where the teacher in charge of the course participates in the design of the sequence.

Description of the Rescue Triangle game

Triângulo Resgate is a quiz type game set on an interactive board that represents the bottom of the sea. There are, on the one hand, a marine species that must be rescued, and on the other a peixorro (a combination of fish and dog) who is a kind of hero to save said species. To cover the secondary school curriculum, the game proposes fifteen levels distributed as follows: the first five refer to the metric relationships of a right triangle, levels six to ten deal with trigonometric ratios and the last five deal with the theorem of sine and cosine. In this work, the metric relationships of the right triangle are studied, and the first five levels of the game are used. The game presents the metric relationships as shown in Figure I.

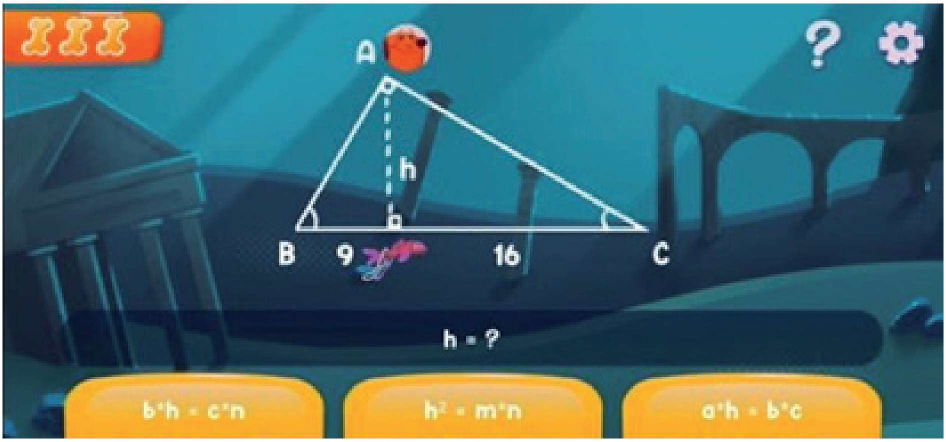
FIGURE 1



Metric relation of the triangle rectangle

Starting from a triangle (Figure 2) with an unknown value that corresponds to the segment that connects the *peixorros* and the marine life, the user must find said value to advance to the next level. To accomplish this, you have three equations that represent relationships between the elements of the triangle, and you must identify and choose the one that allows you to find the unknown value. Upon selecting the chosen equation, a new screen is displayed (Figure 3), and the user must enter all its coefficients using a numerical keyboard available in the interface (including the unknown value).

FIGURE 2



Main screen (Level 1)

FIGURE 3

Emergent screen (Level 1)

Levels one through three use the same right triangle and are differentiated by unknown measurements. Levels four and five propose a triangle of different size and position.

Methodology

This research is ethnographic and descriptive in nature, consisting of a case study of a school year and a teacher. The data obtained are analyzed from a qualitative methodology perspective. The main objective is to design a teaching sequence on metric relationships using this game in the classroom. This includes how the teacher uses the game and the students' mathematical activity.

First, the didactic sequence that integrates the aforementioned digital game was designed and a pilot implementation was carried out over four classes, each two hours long.

The course is part of the 4th year of a public secondary school in Argentina that serves low socio-economic sectors, with 20 students aged 14 to 15.

The mathematics teacher in charge of the course and implementation participated in the design of the sequence together with the research team.

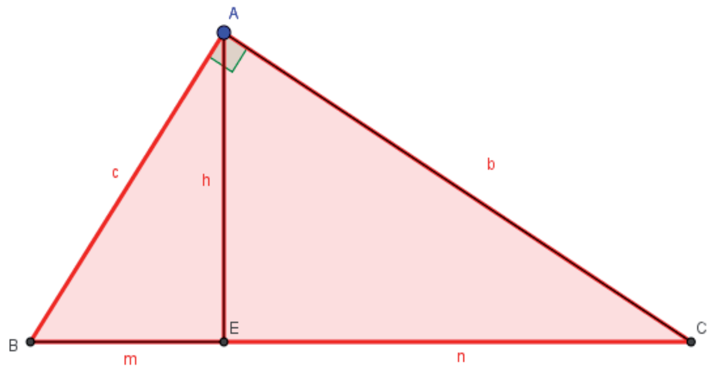
The students had never been part of a mathematics classroom where a digital game was used, nor had they studied triangle similarity or the metric relationships of the right triangle. The students were informed from the beginning that it was a research project, as their consent was requested to participate and to record the classes on video. The data corpus consists of the students' written responses to the proposed tasks, the teacher's field notes, and the audiovisual recordings of the classes. This work focuses on analyzing the students' activity during the development of the sequence that integrates the digital game "Rescue Triangle" in the class, and on its operation, to readapt it for future implementations by this and other teachers.

Didactic Sequence

The task sequence aims to teach the metric relationships of the triangle using the aforementioned digital game and consists of five tasks:

Task 1
With "Triângulo Resgate" game that you have on your cell phone, try to pass the first 5 levels.

Task 2
If the triangles were right angles, how can similar triangles be generated?

Task 3
Starting from triangle ABC in Triângulo Resgate  How could we prove that the triangles in the figure are similar?

Task 4
Based on the similar triangles considered: How could we justify the formulas used in the game?

Task 5
Create and design new levels of a Triângulo Resgate game in a non-digital medium.

Analysis of implementation results

Task 1

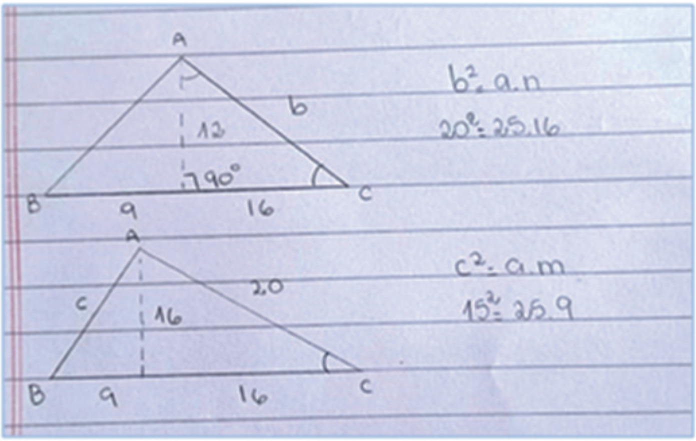
In the first class, Task 1 was completed. The students individually played the first five sequential levels of the game, focusing on the metric relationships of the triangle. They progressed at their pace and could use their calculators if they wished, as shown in Figure 4.

FIGURE 4

Students play and write the calculations and formulas in their folders

The protocols in Figures 5 and 6 illustrate how the students solved each level related to the game. They identified the known elements, substituted them into the formula, calculated the unknown value either mentally or with the calculator, and performed the verification by substituting the values back into the corresponding formula.

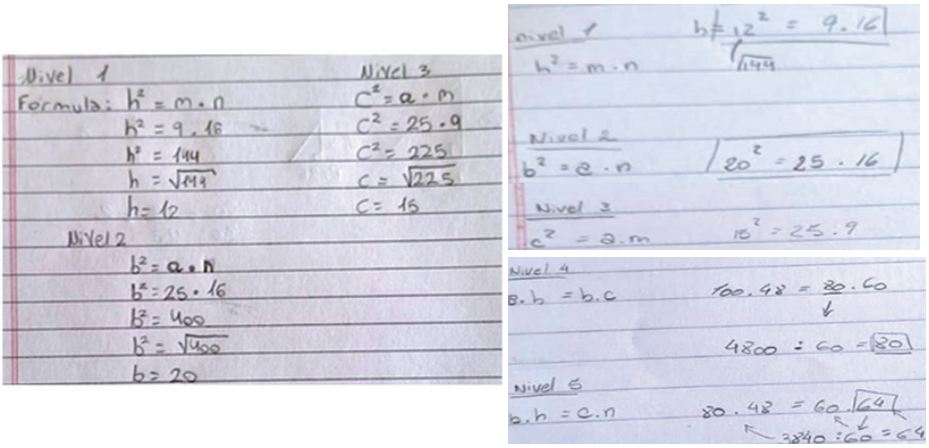
FIGURE 5



Response protocols at the first level

At the end of this task, in which the teacher did not intervene, she encouraged and led a sharing session. Her interest was to know if the students had identified the objective of the game, if they had found it difficult to understand how it worked, and if they had enjoyed this type of work in the classroom.

FIGURE 6



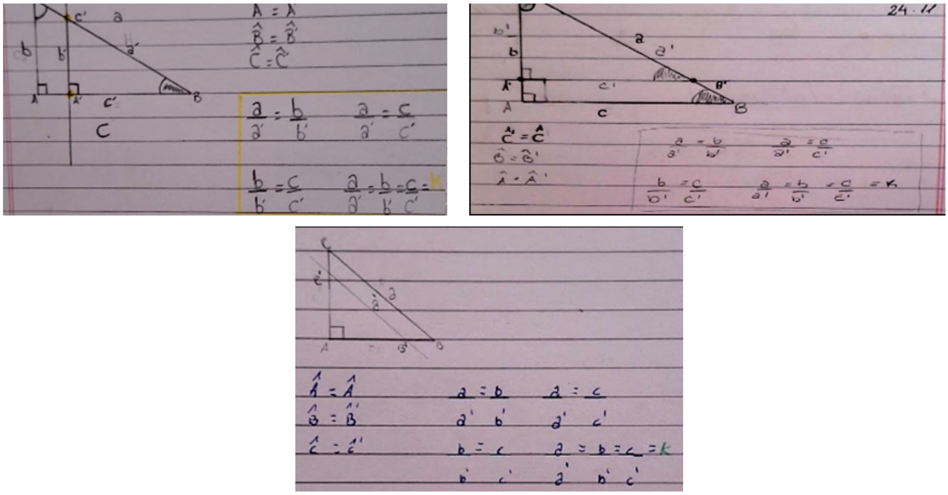
Solution of levels 1 to 5 of Triângulo Resgate

The students expressed their liking for the game and clearly mentioned that their objective was to "rescue the trapped fish", which required calculating the sides of a right triangle using the available information and deciding which formulas to apply in each case.

Task 2

In this task, students were able to interpret the definition of similarity in general, identify congruent angles, and homologous sides between similar triangles. The teacher then asked and led a brief discussion around the question, "Given a right triangle, how can triangles similar to it be constructed?". The students proposed drawing lines parallel to the sides of the triangle and did so for each of them. In this way, they verified that other triangles could be constructed that, although they had sides of different measurements, preserved the angles and ratios between the sides. Figure 7 shows some protocols with the constructions and proportions between the homologous sides made by the students. It is noted that the cases corresponding to the drawing of a parallel to each side of the triangle, including the hypotenuse, were analyzed.

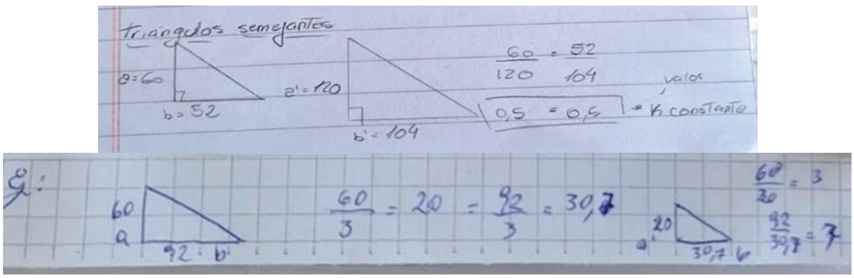
FIGURE 7



Constructions and justification of similar triangles

In addition to expressing the reasons in general terms, the teacher asked the students to propose numerical examples specifying the side lengths. This was done so that the students could understand that the same constant of proportionality existed in all the ratios for the pairs of triangles they considered, as shown in Figure 8.

FIGURE 8

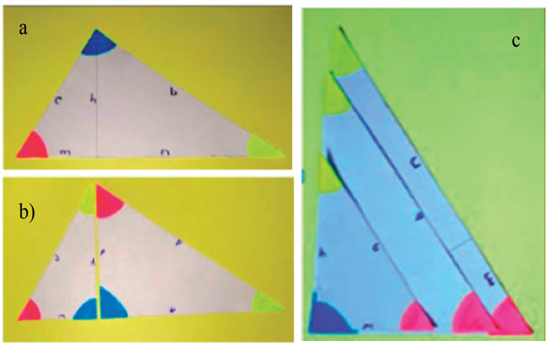


Examples of specific similar triangles proposed by students

Task 3

In this task, students were asked to return to the "Triângulo Resgate" game to answer the question: How can we prove that the triangles in the figure are similar? This requires analyzing the proposed triangles, as shown in Figures 2 and 3, and testing the similarity by identifying the congruent angles and writing the proportions between the homologous sides. Since the triangle on the game screen is resting on its long side, the hypotenuse, which could make it difficult to recognize the homologous elements, the teacher suggested that the students replicate the triangle on paper and section it. This facilitated the identification and notation of the elements of the triangles. The students replicated the triangle from the game and identified the sides and angles (a). Then, they duplicated the triangle (a) and sectioned one of the copies starting from the height corresponding to the hypotenuse. In these two new triangles, they again identified the angles using the same colors to recognize congruent angles (b). Finally, with the three triangles they had, they rearranged them to recognize the parallel sides according to what was done in Task 2. An example of these actions is shown below in Figure 9.

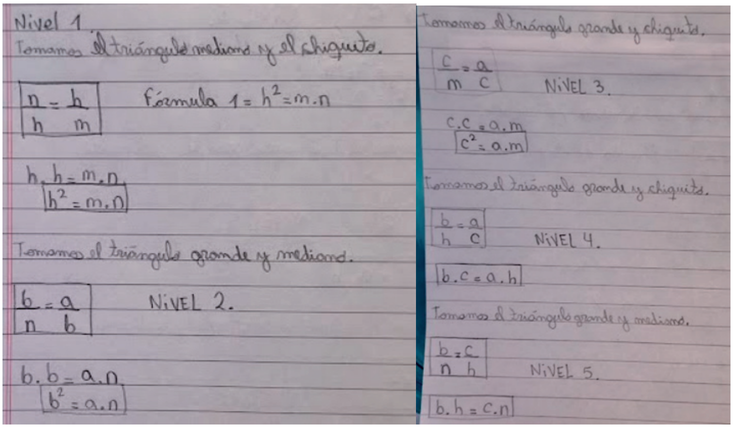
FIGURE 9



Triangles on paper made by different students

Task 4 asks students to derive and justify the formulas for the metric relationships used to overcome the first five levels of the game. This task was unusual for both the students and the teacher, as in Argentine secondary schools, teachers typically impose formulas without justification. However, the students successfully wrote the relevant proportions and derived the same formulas proposed in the game, as seen in the protocol in Figure 10. This figure shows that, to write the proportions between the homologous sides, the students referred to the paper triangles constructed in Task 3 (Figure 9), saying things like, "*We take the medium triangle and the small one*". They chose the appropriate pairs of triangles, involving the sides present in the formulas, to justify them.

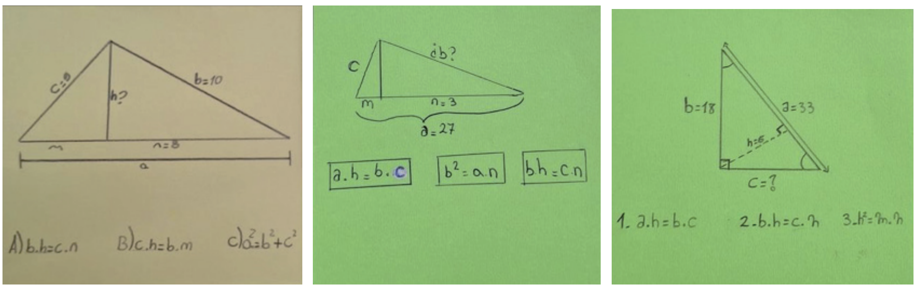
FIGURE 10



Deduction of the Metric relationships of the triangle rectangle

Finally, in Task 5, during the fourth class, the students had to create their own game using items similar to those in the digital game but designed by them. The teacher provided the students with cards to write the items and then play. Additionally, the students had to establish the rules of the game. The items were solved and developed in their notebooks, and then the students created the cards, deliberately omitting the solutions.

FIGURE 11

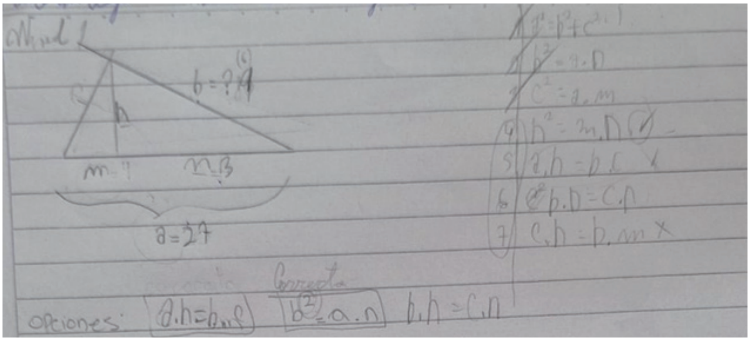


Cards created by the students

This task was carried out in nine groups of two students each. Four groups of students generated cards very similar to those proposed by the digital game. In Figure II, the cards with triangles are shown in the same position as in the original game.

Figure 12 shows that, to generate the cards, the students had to choose which and how many known values there would be. The three possible formulas they selected were correct, and they discarded the others.

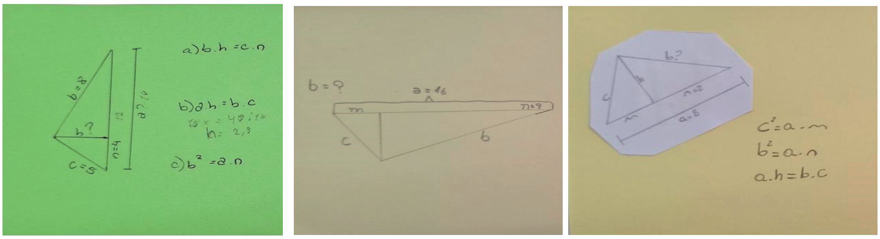
FIGURE 12



Solution for the game item on the proposed card

On the other hand, the remaining five groups established an additional level of difficulty in the cards they generated. In this case, they modified the positions of the proposed triangles to make the item more challenging. Here, the triangles are not "resting" on one of their sides but on a vertex, as shown in Figure 13.

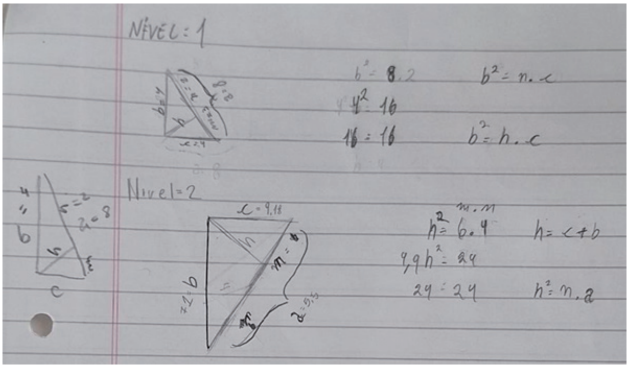
FIGURE 13



Cards with rotated triangles

Figure 12 shows that some students first made the triangle on a piece of paper and then glued it rotated. In Figure 14, it is observed that the student rotates the proposed triangle for level 1 and level 2 of the game.

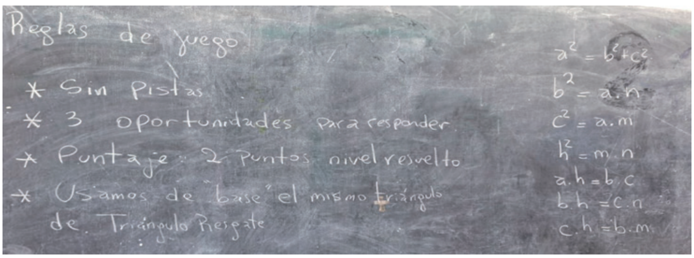
FIGURE 14



Solutions for rotated triangles, regarding level 1 and 2 of the game

Although the students resolved the case they were going to propose during the development of the card, meaning they previously knew the expected solution, they had to choose the remaining formulas to place on the card as distractors. Knowing that these were not appropriate. These are cognitive and metacognitive actions, which reveal their knowledge about metric relationships and their ability to apply them in new, more complex situations than those contained in the game. Finally, in this last class, the students played enthusiastically with the cards, following the rules they had generated. Figure 15 presents a photograph of the classroom blackboard, where they placed the rules for playing. The rules are: do not give "clues", there are three opportunities to respond, each solved level gives two points, and the same triangle suggested by the game must be used as a base. To the right of the blackboard are all the formulas for the metric relationships of the triangle, including the Pythagorean Theorem.

FIGURE 15



Rules of the game proposed by the students

This last task, which requires generating new levels from the digital game to create something new, serves as both a synthesis and evaluation activity, which cannot be done without the relevant knowledge. We also emphasize that, although the task is directly related to the game and the knowledge involved, it also requires transformations of knowledge by generating a different situation, which is an appropriate form of learning evaluation. In other words, the creation of the cards operates as an evaluation of what was learned in the sequence, its effectiveness, and the role of the digital game in the didactic sequence.

The sequence tasks are supported by the game on several occasions: in Task 1, in Tasks 3 and 4 when they must test the formulas, and at the end, to create their own cards. Additionally, it is observed that the students play the first five levels of the game again at that time. In general, in all the protocols, it is seen that the students make explicit reference to some level of the game. That is to say, *"Triângulo Resgate"* underlies all the mathematical activity carried out by students, it is motivating and gives meaning to the study of metric relationships, which leads to learning them.

Final remarks

In this work, a didactic sequence was designed based on the digital game *"Triângulo Resgate"* to teach and learn the metric relationships of the right triangle. The sequence was implemented on a pilot basis with 20 students from an Argentine public school serving lower-middle sectors. The results of the implementation show that the students used the digital game fluently. Through the sequence and the similarity of triangles they learned, they managed to obtain and justify all the formulas of the metric relationships of the triangle contained in the game.

The results are consistent with studies affirming the motivating role of the game (Liu et al., 2021; Sung et al., 2017) and show that, by integrating it into an appropriate didactic design, it is possible to leverage these advantages to have students justify relevant geometric formulas and properties, which are otherwise imposed on them without meaning. Additionally, students had to generate a similar, non-digital game. In this task, most students went beyond the knowledge proposed in the digital game, designing more complex tasks that involved rotating the triangles to make it more difficult to recognize their elements relevant to deciding which formula to use. These actions are clear indicators of learning. The sequence requires students to return to the digital game repeatedly, which helps solidify the knowledge learned about triangle similarity and metric relationships.

This pilot experience is also of interest in teacher training, as it shows the possibilities of integrating the game into the mathematics classroom with other mathematical activities such as demonstrating and justifying. This is relevant because, as documented in other works, teachers generally recognize the student's interest and benefits of games, but when using them in their classes, they limit them to exercises, wasting the potential these resources must modify traditional forms of teaching centered on the teacher. In summary, the results show the potential of this digital game for smartphones in the teaching and learning of the metric relationships of the triangle by integrating it into a constructivist didactic sequence. This result challenges us and invites us to continue exploring this direction with both students and teachers.

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