ISSN: 2444-250X | ISSN-e: 2444-2887

Ramath: mathematics teaching app

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Abstract

This paper presents the Ramath mobile application (app) and its second version using a head mounted display (HMD). Both use augmented reality with the support of game play mechanics in a non-game application, oriented to help 12 to 15 years old students (male and female) to learn several math subjects. We associate concepts such as «gamification» and «problem-based learning» (PBL) within the app, making the subjects much more interesting to the students and encouraging them to be fearless of math by taking advantage of the humans' psychological predisposition to engage in gaming. With the collected information from the research and the help of a predictive algorithm, we try to show how much the technology can help in education.

Keywords: augmented reality; immersive technologies; head mounted display; mathematics; gamification; education; technology uses in education; computer simulation; problem solving.

Received: 01-04-2022 | Accepted: 15-09-2022 | Published: 07-05-2023

Citation: Argüelles Cruz, A. J., Cortés Díaz, H. D. and Piñal Ramírez, O. E. (2023). Ramath: mathematics teaching app. *Tecnología, Ciencia y Educación, 25,* 93-110. https://doi.org/10.51302/tce.2023.2800

ISSN: 2444-250X | ISSN-e: 2444-2887

Ramath: aplicación móvil para la enseñanza de matemáticas

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Extracto

Este trabajo presenta la aplicación móvil Ramath y su segunda versión utilizando un *head mounted display* (HMD). Ambas usan la realidad aumentada con el apoyo de mecánicas de juego en una aplicación no lúdica, orientada a ayudar a estudiantes (hombres y mujeres) de 12 a 15 años a aprender varias asignaturas de matemáticas. Asociamos conceptos como la «gamificación» y el «aprendizaje basado en problemas» (ABP) dentro de la aplicación, haciendo que los subproyectos sean mucho más interesantes para los estudiantes, animándolos a no tener miedo a las matemáticas, aprovechando la predisposición psicológica de los humanos a participar en juegos. Con la información recopilada en la investigación y la ayuda de un algoritmo predictivo, tratamos de mostrar hasta qué punto la tecnología puede ayudar en la educación.

Palabras clave: realidad aumentada; tecnologías inmersivas; casco de realidad aumentada; matemáticas; gamificación; educación; usos de la tecnología en educación; simulación por computadora; resolución de problemas.

Recibido: 01-04-2022 | Aceptado: 15-09-2022 | Publicado: 07-05-2023

Cómo citar: Argüelles Cruz, A. J., Cortés Díaz, H. D. y Piñal Ramírez, O. E. (2023). Ramath: aplicación móvil para la enseñanza de matemáticas. *Tecnología, Ciencia y Educación*, *25*, 93-110. https://doi.org/10.51302/tce.2023.2800

Summary

Nota: los autores del artículo declaran que todos los procedimientos llevados a cabo para la elaboración de este estudio de investigación se han realizado de conformidad con las leyes y directrices institucionales pertinentes. Asimismo, los autores del artículo han obtenido el consentimiento informado (libre y voluntario) por parte de todas las personas intervinientes en este estudio de investigación.

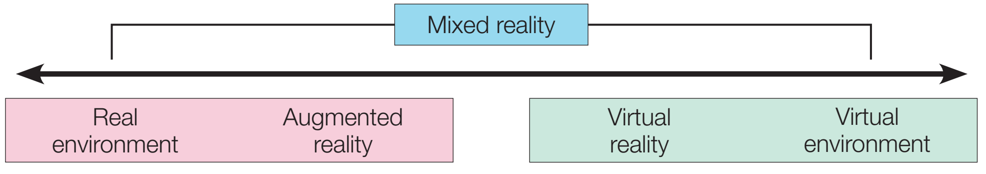
1. Introduction

There is a trend in recent years where students are asking how the topics they see in school can help them or how they will use them in real life, especially in areas where complex and abstract topics are shown. We often hear the question «When will I use math?» from students from elementary through high school. This may seem like a minor problem, but it is a fact that children and adolescents of recent generations are not interested in science-oriented careers. This causes a stagnation in the development of science and technology, which leads to a strong impact on social and economic development. Research shows that these problems begin between the ages of 12 and 15, so we will focus on the subjects and topics taught in school during this age period (Estapa and Nadolny, 2015).

With the emergence of the pandemic, as humanity learns to adapt to it, scientific and technological development in various areas began to accelerate. As technologies evolve, new ways of interacting with them are developed every day, making everyday activities more attractive and easier for people to perform. This also applies to education as there is a need to study from home or other places far from a classroom, where there are various restrictions to bring knowledge closer. Because of this, immersive technologies are becoming more relevant, which can be defined as technologies that, using hardware such as video cameras or audio speakers to replicate a physical experience, simulate an environment or add digital information (Argüelles *et al.*, 2021).

Another factor associated with immersive technologies is the massification of recent innovation placed in mobile devices such as cameras, accelerometers, gyroscopes, biometric sensors, among others, as well as the emergence of commercial HMD. All this technological progress is driving the development of immersive technologies in various areas of daily life, such as manufacturing, industrial maintenance, health, education, among others. Immersive technologies can be divided into three categories like shown in the figure 1.

Figure 1. **Immersive technologies**



Source: own elaboration.

Virtual reality, the idea of this technology is to recreate a different environment, to make the user believe it is immersed inside the scenario (Evans, 2018). Augmented reality works in the «real environment». This is, augmented reality is the immersive technology that adds information to the real world, this enriches the real world with digital and multimedia information, such as 3D models and videos, overlaying in real-time the camera view of your smartphone, tablet, PC or glasses (Arnaldi *et al.*, 2018). Mixed reality (MR) is a combination of both AR and VR, the idea is to use one or another when it is more convenient (Weng *et al.*, 2019).

Each of these technologies has its own advantages and disadvantages, however, by allowing teachers to share their knowledge visually with 3D virtual projections that are interactive, it helps students develop skills such as concentration, reasoning and creativity, leading to a better understanding of complex subjects and seeing how they can be used outside of the classroom (Scavarelli *et al.*, 2021).

This work is divided into two different apps developed to evaluate augmented reality in an educational context. The application is called Ramath which comes from augmented reality and mathematics. The first application consists of a mobile application for the visualization of theoretical and practical information on three specific topics: geometric figures, Pythagorean theorem and operations with fractions. Concepts and problems are represented with dialogue balloons and 3D figures. Each topic begins with a problem to be solved. To solve the problem, the student needs to go through each lesson that explains a specific concept to solve the initial problem. After watching each lesson, the student will try to solve the initial problem, with the option to go back to the lessons to consult any concept.

After some experiments and based on this first application, we developed a second version of this app designed and developed to be used with HMD, it has the name of Ramath 2.0.

Augmented reality should be considered as a tool that helps and complements traditional teaching and learning methods, it encourages the idea and dynamics of teamwork, creativity, spatial awareness, etc. It is important to note that the idea of using augmented reality is not to replace teachers or classrooms, but to enhance and contribute (Garzón *et al.*, 2020; Randel *et al.*, 1992).

To complement the use of augmented reality, a teaching method is used to design the lessons and the way users can navigate through the application. One of the most relevant methods to work with is PBL. It is based on the use of complex real-world problems as a vehicle to promote students' learning of concepts and principles, rather than a direct presentation of facts and concepts. In addition to course content, PBL can promote the development of critical thinking skills, problem-solving abilities, and communication skills (Fidan and Tuncel, 2019).

Moreover, to stimulate the user's senses and make the learning process more interesting and fun, game mechanics will be added to the application, such as earning points for performing activities and interactive 3D models and scenarios, which is called gamification. Karl Kapp defines «gamification» as the implementation of game mechanics for non-game applications to encourage people to adopt the applications. It is also about encouraging users to adopt desired behaviors in relation to the applications. Gamification works by making technology more appealing and encouraging desired behaviors by tapping into the psychological predisposition of humans to engage in games to gain benefits. This technique can encourage people to perform tasks that they normally find boring, such as taking surveys, shopping, or reading web pages (Kapp, 2012).

1.1. Related work

The scope of this work is the development of an augmented reality application for mobile and HMD used in educational environments applied to mathematics. Previous work has already considered the use of augmented reality in this field. For example, Yoon *et al.* uses augmented reality to teach students Bernoulli's principle, as the authors themselves say, it is a challenging scientific concept, the results show that students who used and interacted with augmented reality had greater knowledge gains (Yoon *et al.*, 2017). Kaur *et al.* (2018) developed an augmented reality web application with the proposal to teach 3D geometry concepts and improve visualization skills of high school students. The study by Hanafi *et al.* (2017) suggested that augmented reality could improve motivation in learning subjects due to lack of confidence and practice. A similar application to Ramath's is the work of Lucas *et al.* (2018), their results suggest that the use of augmented reality generates enthusiasm in students and highlight the accessibility and ease of use of the application.

The relationship between augmented reality and education is addressed in the work of Wu *et al.* (2013), who suggest that augmented reality could help learners conduct authentic exploration of the real world, and that virtual objects, such as texts, videos, 3D models, and images, are complementary elements for learners to conduct research on the real-world environment. Second, the use of augmented reality technologies can be extended to the integration of real-world and digital learning resources. The idea is not to replace traditional learning, but to use augmented reality as a complementary tool.

Meta-analysis studies were conducted between 1992 and 2011 to compare the effects of games and simulations with traditional classroom instruction in terms of student performance. The work by Dimitrov and Rumrill (2003) comprises 67 studies and their main findings were that 56 % of the experimental population showed no difference between games and conventional instruction, but 32 % favored games, while 5 % favored conventional instruction. The analysis by Wolfe (1997) comprised seven studies; they found that games were considered more interesting than conventional instruction. The game-based approach produced significant increases in knowledge level over conventional case-based teaching methods.

In the work of Hays (2005), 105 different studies were analyzed, and their main conclusions were that an instructional game will only be effective if it meets the specific instructional objectives and is used as intended. Instructional games should be integrated into instructional programs that include information and feedback. The use of instructional support to help learners figure out how to use the game increases the instructional effectiveness of the game experience. At the same time, instructional designers play a keyrole to design the games.

Vogel *et al.* (2006) analyzed 32 studies and found that greater cognitive gains were observed in subjects using interactive games versus traditional teaching methods (although simulations yielded a stronger result). Better attitudes towards classroom learning compared to traditional teaching methods. The level of realism of the images in the software does not seem to have an impact.

Ke (2009) performed an analysis of 600 studies and showed that the effects of learning with games were positive in 52 % of the studies examined. Sitzmann (2011) found, after analyzing 65 studies, that confidence with games was 20 % higher. Declarative knowledge was 11 % higher for students taught with simulation games. Procedural knowledge was 14 % higher with simulation games. Retention was 9 % higher with simulation games.

Augmented reality can be used to add complementary information to texts, books or any material used in classrooms or to add interactivity between learners and the object of study and enrich the educational environment. For example, Lytridis and Tsinakos (2018) implement ARTutor, it is a mobile application that consists of the idea of education textbooks, enhanced by adding digital content to them, viewing digital content and retrieving information from books by asking questions in natural language. Or the work of Werrlich *et al*. (2018) designed for early childhood education reading, which combines augmented reality and multimedia to achieve information enhancement of books.

These studies show that the use of augmented reality and the incorporation of different pedagogical methodologies, such as PBL and game mechanics can help to improve learning, we can use these ideas in mathematics, due to the abstract nature of all related subjects, so using augmented reality as a visual representation of the contents presents a good opportunity to implement it.

2. Objective

Develop an auxiliary tool that implements augmented reality and PBL methodology to help students understand and comprehend abstract and complex mathematical topics, compare the mobile version of the app and the HMD version to analyze the data obtained.

3. Methods

3.1. Hypothesis

The use of augmented reality applications as an auxiliary tool can help in the learning process of abstract and complex subjects not only help and elevate what is learned and understood, but with enough time of use and practice of knowledge, make users raise their grades and skills in school.

3.2. Development

To understand the differences between the two versions of the app developed it is important to notice and realize the process involved in each one and the methods used.

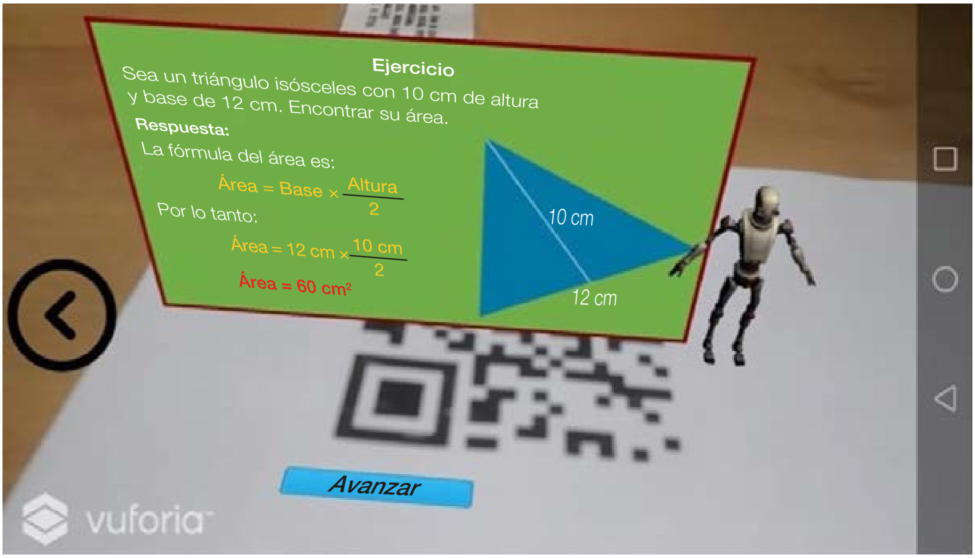
The first version of Ramath consists of an augmented reality-based mobile application developed in Unity for Android devices. It is used for the visualization of theoretical and practical information on three specific topics: geometric figures, Pythagorean theorem and operations with fractions. Concepts and problems are represented with dialogue balloons and 3D figures. Each topic begins with a problem to be solved. To solve the problem, the student needs to go through each lesson that explains a specific concept to solve the initial problem. After viewing each lesson, the student will attempt to solve the initial problem, with the option to go back through the lessons to look up any concept. Navigation is done through buttons that the user must press. These topics were chosen from the syllabus.

Ramath 2.0 is an application developed for head-mounted augmented reality displays, it was developed in Unity using the Meta development kit, in this one the same topics of the first version are used, but the problems presented change, to take advantage of the processing and the different types of interactivities that can be done with the HMD. The navigation through the map follows the same steps, but it is done with virtual buttons. The themes developed in this version are the same as in the mobile application.

Ramath uses Vuforia as software development kit (SDK) to implement augmented reality, QR codes are used as targets that the user must focus on with the mobile camera, so that the information and 3D figures associated with it appear, as seen in figure 2. Each target has a specific lesson of a specific topic, for example, there is a target that shows how to calculate the volume of a pyramid. Once the information and 3D figures have been displayed, the user can move freely in space to view the information and figures at different angles.

> Hypothesis: the use of augmented reality applications as an auxiliary tool can help in the learning process of abstract and complex subjects

Figure 2. **Ramath navigation**



Source: own elaboration.

Ramath 2.0 is designed to be used in the Augmented Reality HMD from Meta. Therefore a SDK for development in this HMD is used, it works in Unity and can be exported direct to the HMD. The development platform is Windows Universal Platform.

The 3D models that make up the scenarios are displayed in a 360-degree field of view around the user. With this approach, people can select and navigate through the different possible problems

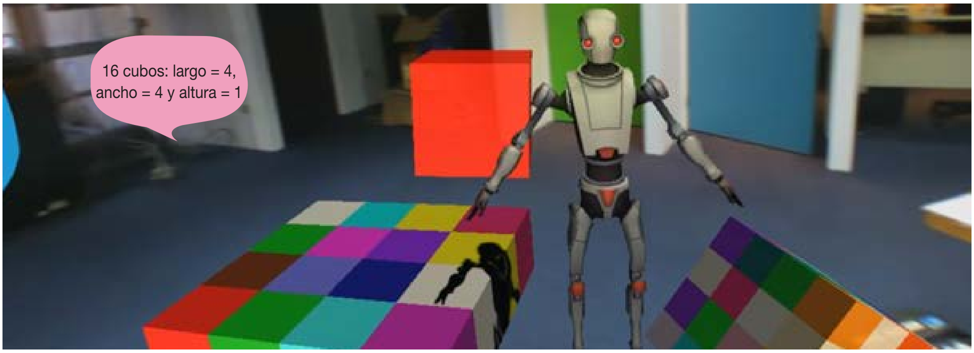
The 3D models that make up the scenarios are displayed in a 360-degree field of view around the user. With this approach, people using the HMD can select and navigate through the different possible problems and scenarios. If the user is

Figure 3. **Augmented Reality HMD from Meta**

Source: MetaVision.

interested in one of them, he or she can manipulate the objects using only his or her hands and if desired can access that specific issue with the associated virtual button. The 3D models were developed with Blender, the avatars used correspond to a Unity 3D model package.

Figure 4. **Ramath 2.0 navigation**



Source: own elaboration.

In both versions of Ramath, we use the PBL to define the structure of the lessons and the order of appearance. In each topic, we show the main problem to be solved, as seen in figures 5 and 6. Next, the application shows all the concepts, formulas and some examples needed to solve the problem. Finally, the main problem is shown but now with some answers that we can choose. In case the answer is wrong, we can try again or go back to some of the concepts, formulas and examples.

Figure 5. **Ramath**

Source: own elaboration.

Figure 6. **Ramath 2.0**

Source: own elaboration.

To test the idea of using immersive technologies and, specifically the Ramath proposal, we designed two groups: control group and experimental group. We collected data from 20 randomly selected participants, 10 of them were part of the experimental group and the other 10 of the control group, all of them belong to Mexico City and were 14 years old at the time of the test. They solved a test consisting of 11 questions related to the selected topics to make a comparison between the scores of both groups. The control group solved the exam without using the app. The experimental group interacted with the app and used the contents to solve the exam.

The variables identified in this case study were:

- **Dependent variable.** Student's grades.
- **Independent variable.** Ramath's use.
- **Quantitative variable.** Grades from the test exam.

Statistical analysis we use a linear regression model to make a prediction of how much Ramath users can raise their grades in school. It allows us to find the expected value of a random variable *a* when *b* takes a given value (Kaliciak *et al.*, 2017). This model has the problem that all the results obtained from it will be linear, but students' grades are never linear, so we chose to use Holt's trend method to obtain a much more accurate model.

Holt's trend method (Trull *et al.*, 2020) extended simple exponential smoothing to allow forecasting of data with a trend. This method involves a forecast equation (1) and two smoothing equations, one for the level (2) and one for the trend (3) (Koehler *et al.*, 2001).

In (1) and (2) C_x its the average, α and β are the smoothness parameters, Y_x the value of the sample. In (3) R_x it's the expected value.

$$C_x = \alpha Y_x + (1 - \alpha)(C_x - 1 + b_x - 1) \quad (1)$$

$$b_x = \beta (C_x + C_x - 1) + (1 - \beta) b_x - 1 \quad (2)$$

$$R_x = C_x + b_x \quad (3)$$

4. Results

In table 1 and table 2 we show the results for both groups. Two questions were asked to the participants of the experiments. The experiments consider important whether users like or dislike video games, since Ramath implements game mechanics, so it is important to notice if doing something they like and do on a regular basis modifies their behavior towards mathematics.

By grades we refer to the last three bimonthly grades they have obtained in mathematics. We can observe that there is a difference of 1.80 % between the groups in the average test scores, we can assume that the difference is due to the use of Ramath in a controlled environment. For this purpose, we have only used the first version of Ramath, since the Meta AR HMD are for research purposes only.

After the statistical analysis and the predictions by linear regression and Holt method are made, the results are shown in figure 7. The values for the prediction are compared to the average value obtained from the grades of the participants in the experiment.

Both the statistical analysis and the predictions were developed using linear regression and Holt's method, obtaining the results shown in figure 7. The prediction values are compared with the mean value obtained from the scores of the participants in the experiment.

Table 1. **Experimental group results**

Like for mathematics	Like for videogames	1st grade	2nd grade	3rd grade	Test
Yes	No	7.4	7.6	9	4.5
Yes	Yes	8.3	10	10	4.5

Like for mathematics	Like for videogames	1st grade	2nd grade	3rd grade	Test
No	No	10	7.9	10	4.5
Yes	Yes	9.1	8	9.5	4.5
Yes	No	8.2	10	9.5	3.6
Yes	Yes	7.1	6	8.9	3.6
Yes	Yes	9.6	8.1	9.8	3.6
Yes	Yes	8.2	6.6	10	3.6
Yes	Yes	7.1	8.4	9.1	2.7
Yes	Yes	9.2	8.6	8.8	2.7
Average		8.42	8.12	9.46	3.78

Source: own elaboration.

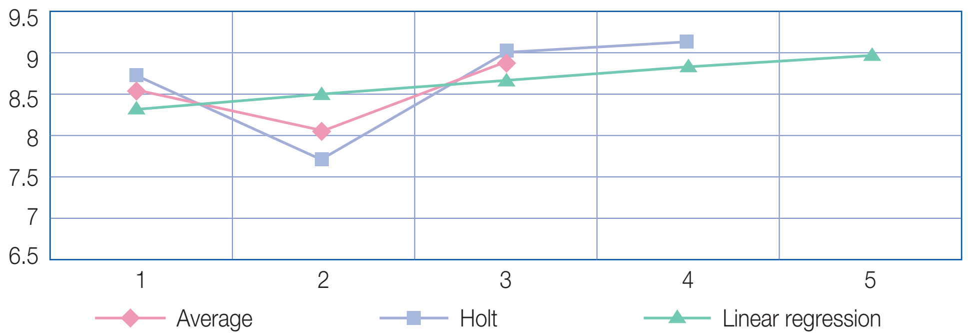
Table 2. **Control group results**

Like for mathematics	Like for videogames	1st grade	2nd grade	3rd grade	Test
No	No	10	7.6	8	6.3
No	No	8.2	7.8	6	6.3
No	No	9.2	10	9.1	4.5
No	No	7.2	6.5	9	4.5
No	Yes	8.4	7.3	7.8	3.6
No	No	9	10	9.8	3.6
Yes	Yes	7.6	7.4	9.2	3.6

Like for mathematics	Like for videogames	1st grade	2nd grade	3rd grade	Test
Yes	Yes	10	6.3	7	3.6
Yes	Yes	9.5	9.2	9.4	0
No	Yes	7.2	7	7.5	0
Average		8.63	7.91	8.28	3.6

Source: own elaboration.

Figure 7. **Comparison of the predictions**



Source: own elaboration.

5. Discussion

After testing, we applied the predictive models to all data, without distinguishing between groups. We show the mean scores of all participants with the 1.80 % improvement derived from the experiment. We used the grades as input for linear regression and Holt's predictive model. With this, we were able to predict grades up to two bimesters. In table 1 and table 2 we can see the results of the linear regression model, the Holts predictive model, the comparison of both predictive models and the average grade of all students.

There is an improvement of about 1.80 % between the two groups that took the test. The experimental group had the best results. The only significant difference between the two groups was the use of the app, we assume that the improvement was due to Ramath. The use of augmented reality favored the learning process in the participants who used the app compared to those who did not. These results support the hypothesis proposed in section 3.1, as long as participants keep using the tool, things learned and therefore school grades increase. All participants, no matter which research group they belonged to were able to keep the app on their phones, so they can continue to use it and the updates that are developed will be delivered to them, so in the near future, we can go back to them and analyze how they are performing and review the data they generate from the use of the app.

It is also important to note that almost all the participants in the experiment like to play video games, this helped them to navigate, interact and use the application without any problems. The doubts resolved had more to do with how to answer the test or with specific test questions.

5.1. Future work

As this works shows, the objective was concluded and the hypothesis was correct, still there is a lot of work and research to do in this area of immersive technologies and education. About this work, the next steps are:

- Perform continuous reviews of the participants and the data gathered to compare with the predictions obtained.
- Add more subjects, activities and scenarios related to mathematics, and in a more distant future, add scenarios from other subjects like physics, chemistry, language, and history.
- In a computational sense, improve and optimize the scenarios, 3D models and data gathering inside app so it can run into more Android and IOS devices, also develop optimization in the HMD so the computer needed to run it doesn't require that much computational power.
- Implement a module so professors can develop their own scenarios using a block programming.
- Implement artificial intelligence algorithms in a tutor, so the app learns from students routines and learning methods in order to help them creating personalized routines and tips.

6. Conclusion

Both versions of Ramath have their own advantages and disadvantages. The mobile version is easy to use and install, everyone can do it just by downloading and following the instructions provided by the mobile. Also, it has the advantage that the democratization of technology allows almost every student, adult or child to have one device. Still, there exist some hardware and OS requirements to make the app function. During the experiment it was observed that mobiles started to heat up because of the rendering needed to visualize the 3D models. Other participants had to erase some applications in their devices to install Ramath, the application needs at least 200 MB to be installed. In addition, an internet connection was needed to collect the data, so a hotspot was provided to be able to perform the experiment. Once all the information from the experiment was analyzed, all the recommendations were considered to develop and improve the application to help the students.

Now, the advantages of using and HMD over mobiles as a platform for development that we found are:

- The hardware needed to make the process and rendering of all the elements it's not restrictive because the HMD does all of this on the computer is connected, allowing more complex scenarios and exercises.
- The connectivity needed to store and gather all information is not a problem, as mentioned before, the computer does all this work, so information and protocols can be configured.
- HMD provides a more immersive experience than cellphones.

However, the commercial HMD that can be bought at this moment are not cheap. Of course, when we talk about rendering the models and scenarios we mentioned as an advantage for HMD, but it is also a disadvantage, as mentioned, the rendering process is done in the computer not in the HMD, therefore, to work, they require computers with high requirements, specifically, graphic cards, this is because the HMD are connected directed to them and make all the process needed in them. Also, it is important to notice that not everyone can use the HMD, some people can experience dizziness, fatigue, and blurry vision, even some people cannot adapt to the depth perception the HMD brings, making them unable to work with augmented reality.

All things considered, mobile augmented reality applications nor HMD applications are better for education or learning, it is a tradeoff in which some factors must be considered. However, augmented reality and other immersive technologies have shown to have the potential to be real changers in the educational world and more.

As technologies continue to evolve and develop, there are still obvious needs for augmented reality to be fully incorporated into education and classrooms. Some hardware limitations can be solved by implementing some technologies such as cloud and edge computing. However, by doing this the complexity of developing immersive software and applications rises significantly, therefore, and at this time, only technology developers are involved in creating augmented reality content for education, but this must change, as researchers we must provide frameworks, development and environments and platforms for teachers, parents and students to get involved in creating content, only by doing this can we create robust and inclusive technologies that help people around the world.

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Contribución de autores. A. J. A. C., H. D. C. D. y O. E. P. R. han participado a partes iguales en la elaboración de este estudio de investigación.