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Augmented reality as a possibility as for approach with geometric solids

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ABSTRACT

This article presents qualitative research, which deals with the use of the Solids RA application, augmented reality, for pedagogical purposes, in geometry teaching activities. The objective was to investigate how an augmented reality application can contribute to the understanding of geometric solids by elementary school students. To analyze the results obtained, the significant theory anchored in the qualitative approach was used as a methodological contribution. Particularly there was an interest in understanding how this application could favor the development of students' visualization skills, in order to contribute to the construction of knowledge in geometry. As a parameter for analyzing the results, the concept of meaningful learning was used as a theoretical contribution, considering aspects such as content organization, understanding of concepts and integration of new knowledge with existing knowledge, within geometry teaching. Finally, the analysis of the activities demonstrated that there were signs of student engagement and motivation provided by the visualization of geometry concepts made available by the application, reorganizing the way in which knowledge was constructed by the students involved in this research. The use of the application enabled a response within the conception of meaningful learning theory, as it ensured a change in priority in the construction of concepts of geometric solids, since, instead of prioritizing memorization, they began to give importance to understanding the concepts presented. It was concluded that the teaching of geometry, supported by the use of augmented reality applications, can provide a distinct model for the construction of knowledge.

KEYWORDS: Digital Technologies; Augmented Reality; Geometric Solids.

A realidade aumentada como uma possibilidade para o trabalho com sólidos geométricos

RESUMO

Este artigo apresenta uma pesquisa de natureza qualitativa, que versa sobre a utilização do aplicativo Sólidos RA, de realidade aumentada, com fins pedagógicos em atividades no ensino de Geometria. O objetivo foi investigar como um aplicativo de realidade aumentada pode contribuir para a compreensão dos sólidos geométricos por estudantes do Ensino Fundamental. Para análise dos resultados obtidos, utilizou-se como aporte metodológico a teoria significativa ancorada na abordagem qualitativa. Particularmente havia o interesse em perceber de que forma esse aplicativo poderia favorecer o desenvolvimento das habilidades de visualização dos estudantes, de modo a contribuir com a construção do conhecimento em Geometria. Como parâmetro para análise dos resultados, utilizou-se o conceito de aprendizagem significativa como aporte teórico, considerando aspectos como organização de conteúdo, compreensão de conceitos e integração de novos conhecimentos com os já existentes, dentro do ensino de Geometria. Por fim, a análise das atividades demonstrou que houve indícios de engajamento e motivação dos estudantes proporcionados pela visualização de conceitos de Geometria disponibilizados pelo aplicativo, reorganizando a forma de construção de conhecimento pelos estudantes envolvidos nesta pesquisa. O uso do aplicativo possibilitou uma resposta dentro da concepção da teoria de aprendizagem significativa, pois assegurou uma mudança de prioridade na construção dos conceitos de sólidos geométricos, uma vez que, em vez de priorizarem a memorização, passaram a dar importância à compreensão dos conceitos apresentados. Concluiu-se que o ensino da Geometria, apoiado na utilização de aplicativos de realidade aumentada pode proporcionar um modelo distinto para a construção do conhecimento.

PALAVRAS-CHAVE: Tecnologias Digitais; Realidade Aumentada; Sólidos Geométricos.

INTRODUCTION

The presence and use of digital technologies (DTs) in society has been transforming the means of communication and information in different sectors. One of DTs particularities is the possibility of helping in the practice of simultaneous tasks, with more speed and without need for user presence in the same physical environment. It is possible to visualize a tendency of growth regarding the use of digital devices such as computers and data communication networks, which are more present in society throughout time (Lévy, 2021). Besides that, the expansion of access to DTs reorganized habits and necessities, as the work and social organization of individuals, impacting particularly to scholar reality, bringing new rhythms and dimensions to the tasks of teaching and learning (Kenski, 2018; Motta & Kalinke, 2021).

Specifically in the context of mathematics education, the use of digital resources have presented themselves relevant as a way to awake the interest of students. Some DTs have been used as a proposal for pedagogical mediation in different teaching situations, and, besides, for the philosopher Pierre Lévy (Fernandes, 2020; Lévy, 2021), digital technologies makes possible the construction of knowledge through processes of group collaboration and contribute to the emergence of collective intelligence.

The research group about technologies in mathematics education (GPTEM), describes that in mathematics education, resources have been explored in investigations proposed by researchers in different post-graduation programs, *lato* and *stricto sensu,* and groups of research. In this dynamic, new technologies have been tested and experimented, in seek for comprehensions about its possibilities in the learning and teaching processes in mathematics. In this text, in particular, the possibilities of and Augmented Reality (AR) in these processes, shall be better understood.

Tori (2017) mentions AR as a technology which seeks to create a virtual world apart from the normal one, with the goal of supplementing the real world with virtual objects, generated by computer and coexisting with the real space. In order to explore the virtual scenario in which is inserted or approached a determined content, only a device, such as a smartphone associated to an application, is necessary. Due to its visual characteristics, the ARs open different possibilities of application in teaching, mainly in geometry when regarding mathematics.

Considering the spatial visualization as an important skill of simulation to comprehend and solve problems and knowing that AR makes possible to insert virtual objects in the real world, providing the user a different possibility of comprehending the content, this work seeks to answer the following question: How can an application of AR contribute to the comprehension of geometrical solids by elementary school students?

METHODOLOGICAL PROCEDURES

Aiming to answer the presented question, a qualitative approach was chosen because the research will take place in a natural environment, the researcher will be present in the place, actively participating in the real experiences of the subjects from the research (Creswell, 2014). In order to perform it, a pedagogical strategy was organized contemplating modules of visualization, planification and creation, available in the application. This strategy was based in the three first steps stablished in the methodological process of Amorim (2022) and were adapted according to the goal of the research. Each of the modules allow different interactions with geometrical objects in AR.

To analyze the obtained results, Ausubel (2003) theory of meaningful learning was used. Moreira (2019) defines meaningful learning as:

> [...] um processo por meio do qual uma nova informação relaciona-se com um aspecto especificamente relevante da estrutura de conhecimento do indivíduo, ou seja, este processo envolve a interação da nova informação com uma estrutura de conhecimentos específica, a qual Ausubel define como conceito subsunçor, ou simplesmente subsunçor, existente na estrutura cognitiva do indivíduo (Moreira, 2019, p. 161).

The subsumers considered in this research were the geometrical concepts of point, straight, plan and polygons and expositive reviews were performed. Intending to allow the interaction between subsumers and the concept of polyhedrons, as new information, Sólidos RA application was selected. According to Ausubel (2003, p. 8), the learning of new concepts is the result of "interaction between ideas recently presented and existent relevant ideas (anchored)". To verify the retention process, which results from the relation between previous ideas and new significances developed, different possibilities were observed by students to the constructions made in the application.

The pedagogical strategy was organized following the line of Gutiérrez (1996), who envisioned to identify students' specific visualization skills. The approached skills were: perception fugure-background (act of observing the figure from a complex background); perceptive constancy (not mix characteristics and properties of an object according to movement or characteristics of traces); mental rotation (building mental images or imagine them in movement); spatial relation perception (building relations between observed objects and visual discrimination); observe differences or resemblances between objects, images or mental images.

The activities were published during three classes, in two 8th grade classes of elementary school, in a state school located in the city of Curitiba, Paraná, in October 2023. Each class was composed by approximately 35 students.

SÓLIDOS RA APPLICATION AS NA EDUCATIONAL RESOURCE

The main documents of curricular orientation regarding learning and teaching, as the National Common Curricular Base (BNCC), National Curricular Parameters (PCN) and the Curricular Guidelines of Paraná (DCE), highlight the importance of the use of DT in mathematics teaching. According to the DCE for basic education in mathematics (Paraná, 2008), DTs have been favoring the mathematical experimentation and powering possibilities for problem solving.

According to researchers of technology use in education (Mattar, 2017; Kenski, 2018; Motta & Kalinke, 2021), the DTs may power the processes of teaching and learning. In an expositive class, such resources help teachers and students to build concepts and share knowledge, building an interactive environment to the subjects involved in the educational process.

In mathematics educational processes, one of the thematic that DTs may collaborate is the geometrical visualization. Gutiérrez (1996) defines this visualization as an activity of reasoning based in the use of visual or spatial or visual elements, mental or physical, performed to solve problems or prove properties. The visualization is integrated by four main elements: mental images, external representations, visualization processes and visualization skills (Gutiérrez, 1996, p. 9).

Boaler's studies (2016) agree with Gutiérrez (1996) ideas, highlighting the positive impacts of geometrical visualization to the human cognitive system. Yet, according to Boaler (2016), When students learn through visual models, mathematical comprehension is reorganized, and they have access to new and different comprehensions about that knowledge.

In this sense, AR arises as an alternative by amplifying the possibilities of visualizing mathematical phenomena. The characteristics of AR regarding the projection of visual objects in real environments, contribute to the visualization of geometrical elements that would be complex to be reproduced without the help of digital environments. In this sense, it makes possible to create more instigating forms of interaction to the involved in the mathematics learning and teaching processes.

To Kirner e Kirner (2011), AR provides the insertion of virtual objects in the physical environment, presented in real time to the user through technological devices. In a practical manner, it uses the real environment interface, adapted to visualize and manipulate the real and virtual objects, aiming to provide interactivity with the user mediated by the sensation of realism offered by the digital resource, minimizing the gap between real and virtual.

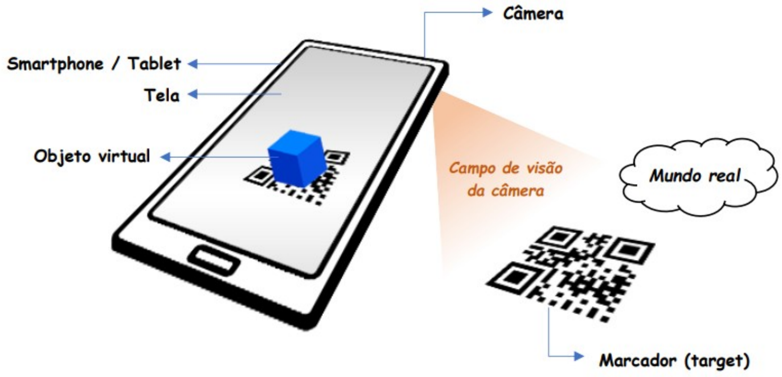
The system is associated to the real world, where virtual components as images, sounds and videos are added and may contribute to a more interactive learning. AR may be explored in a determined environment or real object though digital devices as tablets and smartphones.

Azuma (1997), considers that AR system may have three characteristics: combination between real and virtual objects in the real environment; interactive execution in real time; and alignment between real and virtual objects. AR systems are characterized according to the type of device that is used, involving optical vision or vision by video, originating four kinds of systems: *Video see-through HMD*; *Monitor-Based Augmented Reality* and *Projector-based Augmented Reality* (Kirner & Zorzal, 2005).

Among the characteristics considered by Azuma (1997), for AR systems, the work here presented will discuss the *Projector-based Augmented Reality, which uses real world surfaces where virtual objects' images are projected, as illustrated in figure 1*.

Figure 1

AR for a mobile device.



Source. Amorim, L. L. (2022). Contributions of S*ólidos RA application for the development of geometrical application in augmented reality perspective*. [Monography, Instituto Federal do Espírito Santo]. Instituto Federal do Espírito Santo Repository: https://repositorio.ifes.edu.br/handle/123456789/2406

According to Amorim (2022), the technique of using AR in mobile devices emerged due to the increase of the processing capacity, screen size and for presenting a more accessible price when compared to another devices. In this case, the system adopted, where a camera is used to obtain images from the real world, uniting the image with virtual objects, and presenting this composition of the mobile device screen, making it a tangible model.

Considering the teaching of geometry, these characteristics of tangibility of AR may be relevant when strategically used as resource of mediation, aiming the comprehension of content by students. Therefore, makes possible the experimentation and explore these DTs in education, incentives the development of technical skills and of visualization which has become fundamental in educational context, specifically in math.

Sólidos RA application, which aims the teaching of geometry with use of AR, used in this work, was developed by Amorim (2022) in Instituto Federal do Espírito Santo. In the version used, identified as 4.1, the application presents five functions, or modules: Visualization and planification, Creation, Modeling and Geoplan, exhibited in its initial screen, as illustrated in figure 2.

Figura 2

Starting menu of Sólidos RA and supporting material for activity performing

Source*:* The authors (2023).

To use each of these modules, it is necessary to previously perform the printing of the QR codes available in each of them. Visualization module presents 42 geometrical solids available for visualization and interaction. To use it, the student must point the camera from his device to one of the QR codes. Figure 3 illustrates the visualization and manipulation of one regular hexahedron (cube).

Figure 3

Visualization Module: Manipulation of a cube

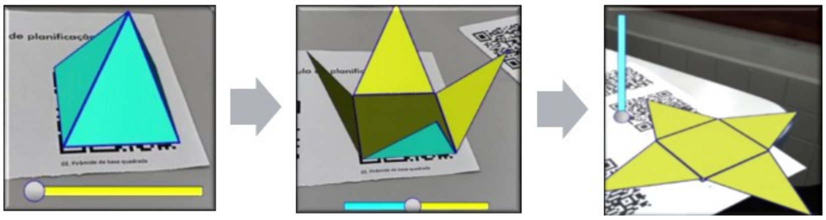
Source*:* The authors (2023).

By pointing the camera to one of the available options, the selected object is exhibited in the screen of the device. The student may interact with it, selecting different faces, translating, rotating and escalating and choosing to exhibit or not the edges and vertices.

In the planification module, illustrated in figure 4, the student may visualize the animation of the geometrical solids planification processes. This module provides sliding controls and movements, that are modified directly through the smartphone screen.

Figure 4

Planification of a square base pyramid



Source*:* The authors (2023).

In the creation module, the student visualizes a system of 3D coordinates with x, y and z modules respectively in colors red, green and blue. This module allows the construction of AR objects through manipulation of geometrical solids and round bodies such as cube, sphere, cylinder, cone, pyramid and semi-sphere, as illustrated in Figure 5

Figure 5

Creation Module

Source*:* The authors (2023).

In the creation of any geometrical solid, the user may click in the desired object icon, and it will be created in the origin of the coordinates. The description of all modules of the application would be extensive and unnecessary for the proposal of this work. Therefore, the modules presented will be the ones used in the pedagogical strategy of this research.

APLICATTIONS IN ACTIVITIES

In the first activity the preparation was made individually, thus, each student received instructions to download the application and how to use each of these modules. Through the activities the students were observed during the activities with the goal of measure the comprehension and pedagogical usability as much as content and interface of Sólidos RA.

Still in the first activity, students received support material and printed QR codes of the visualization module. When questioned if they knew what AR was, most students did not know the term but associated it to games, tridimensional animals available in google and the term 3D.

Afterwards, they received more precise info about what AR was and that they would use it in their smartphones to perform different activities of geometry in those and following activities. In this step, the idea was to explore the creation of plane and tridimensional figures to identify the properties and name them. In this module there is a total of 42 geometrical solids available for visualization and interaction. Since the class was in 8th grade, the solids chosen were cube, regular and square pyramids and prism, which are geometrical structures they had previous contact with.

Visual styles available in Sólidos RA may contribute to recognition of geometrical solids and counting of edges, vertices and faces. Different visual styles, associated with the application of solid rotation, may collaborate with visualization under different perspectives to the student.

Exploring the concept of meaningful learning, after using the application, the participants were asked to answer activity illustrated in Figure 6

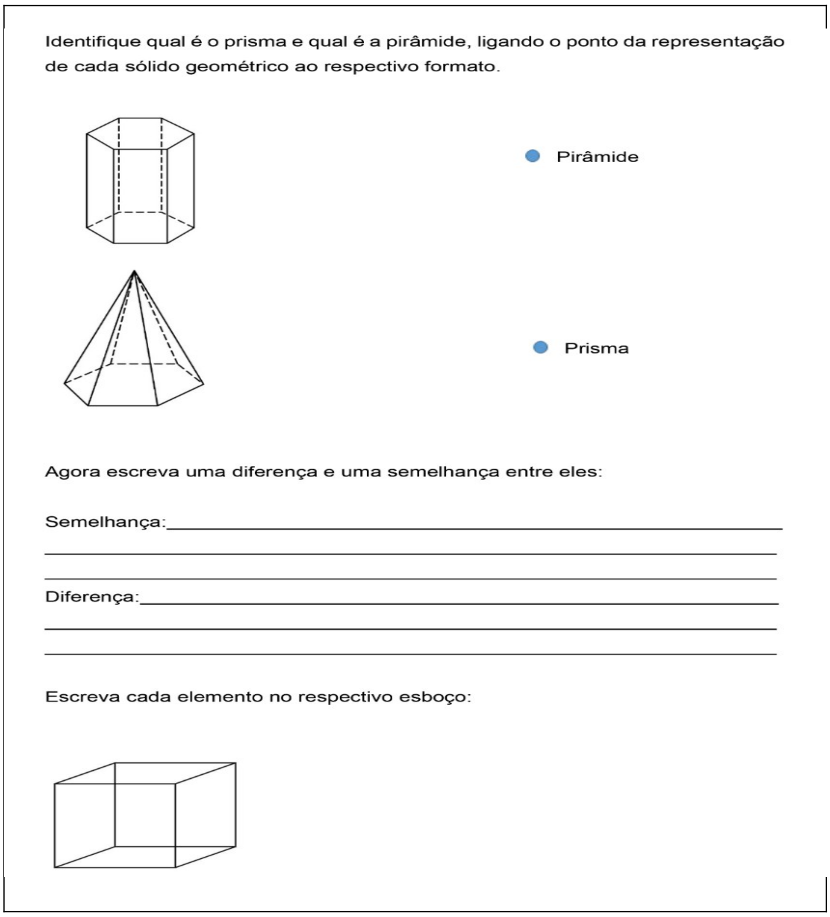
During the retake, before using the application, when showing the cube image, students confused it with the “square” figure, what presented the fact they did not know how to distinguish the difference between plane figures in polygons and spatial figures in polyhedron (cube). This difficulty was discussed in a deeper manner in the next activity.

In the second activity, while working with the planification module, students could see the relation of planification with the respective solid and observe there are many ways to represent planification of the same geometrical solid. Cube, Parallelepiped, prisms and pyramids were worked.

The application Sólidos RA has animation. To obtain it, it is only necessary to click in the colorful bar of the application and the faces of the geometrical solid open and close, changing from the planification of the figure to its spatial form, from bi to tridimensional. This possibility has the potential to aid in the comprehension of the difference between figures of two and three dimensions, what may contribute to extinguish the difficulty presented by students by the end of the previous activity.

Figure 6

Activity proposed after visualization module


Identifique qual é o prisma e qual é a pirâmide, ligando o ponto da representação de cada sólido geométrico ao respectivo formato.

- Pirâmide
- Prisma

Agora escreva uma diferença e uma semelhança entre eles:

Semelhança:____

Diferença:____

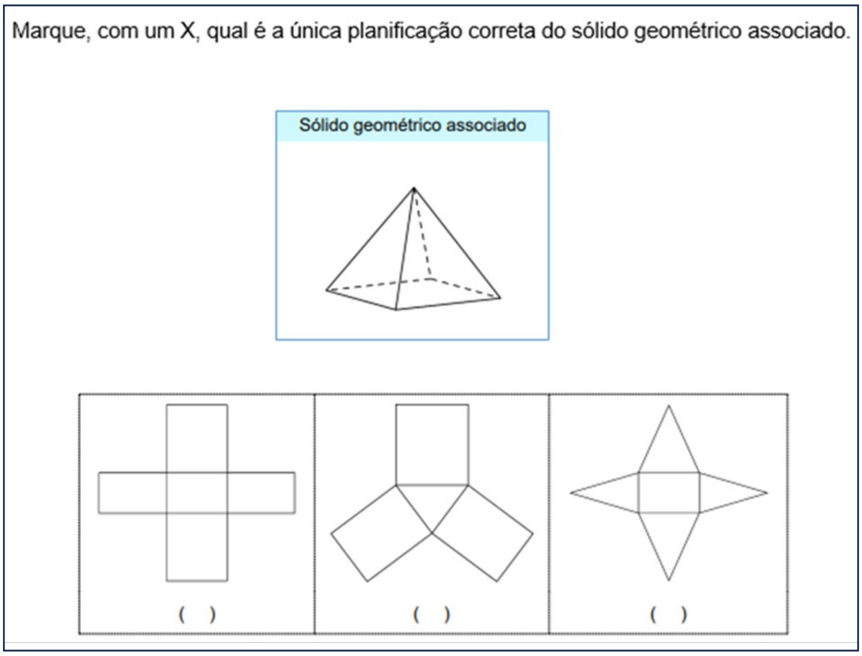
Escreva cada elemento no respectivo esboço:

Source*:* The authors (2023).

Afterwards, figure 7 activity was presented and individually answered without internet help but using their notes.

Figure 7

Proposed activity after planification module



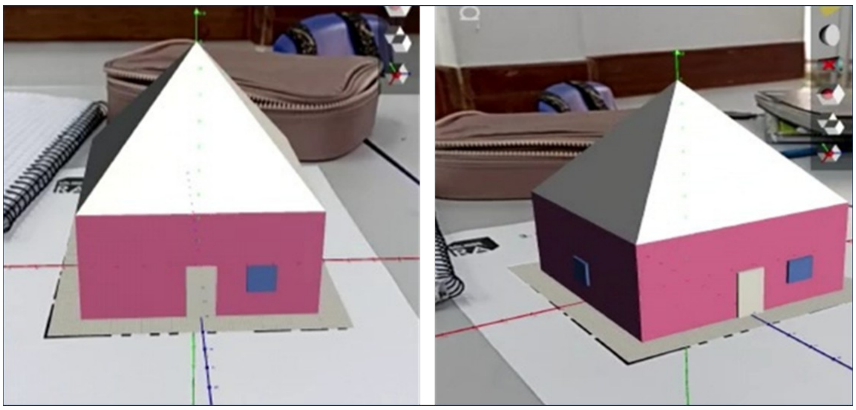
Source*:* The authors (2023).

In the third activity, creation module was presented, producing different scenarios where students may create objects and make transformations by rotating and repositioning. This module interacts with the previous activity's solids (cube and pyramid), allowing translation, rotation and AR scale. Therefore, before providing the printed QR codes, it was necessary to explain about coordinate systems while they used creation module to position the object in space.

When learning to rotate more primitive figures (cube and pyramid), students explored the tools of creation module and were free to build their own scenes, as example there is figure 8.

Figure 8

Activity proposed after creation module application



Source*:* The authors (2023).

In this step, some groups were able to finish their creations and insert details as doors and windows, while others finished only basic structures as the pyramid and the cube.

DATA ANALYSIS

During the application of the activities, it was possible to conclude that the visual styles available in Sólidos RA could contribute to the recognition of geometrical solids and edges, vertices and faces counting. They also created the possibility for the students to explore rotation of solids, identifying and adjusting the visualization under different perspectives.

According to Nokelainen (2006), pedagogical usability regards facilitating learning about materials of an operational system, powering its functions as a system. In AR context, this resource may be integrated to the educational environment aiming to contribute with learning experience.

Regarding content aspects, we sought to identify students' opinions of the used modules. Besides, we sought to number the contents used with the students during the execution of the proposed activities. To comprehend the interface aspect, students were questioned about their opinions about Sólidos RA. The questions considered positive and negative aspects of the application and its interface presentation.

Generally, most students pointed that the application contributed to a better comprehension about geometrical solids content. Students were unanimous when affirming they had not known or used AR before and believed it was easy to learn how to use the resource. One student claimed to have difficulties to follow the activities, however, this is a particular case.

About the use of Sólidos RA in particular, students affirmed they did not find problems to download the application in their smartphones and use it. They indicated however, the application could have other functions and the time for each activity could be bigger. Students also pointed the application could be more colorful and have some adjusts, but, in general, were unanimous in affirming they could visualize geometrical forms in a different manner.

This aspect, according to them, was the one that the application contributed the most since it allowed them to planify a solid and see it in three dimensions. One student indicated that it was not possible to imagine the format from the solid when using only paper, but with the application it was possible. Another student pointed out that he could comprehend the difference between the pyramid and the prism, not yet understood. Another classmate affirmed that it was possible to identify resemblances and differences between those solids.

For being activities that explore axis coordinated in three dimensions, differently from the two the students are used to, the groups not only collaborated with one another but also debated about the values that should be put in the fields of position and rotation modules. Despite a considerable part of the groups presented difficulty about the use of the coordinates x, y and z to translate solids, it was possible to observe that the experience with the creation module was assertive since the groups presented themselves involved and focused on the creation of the scenes.

During the three modules, the creation is the one which allows the biggest creative potential. The group that created the images of the house illustrated in figure 8 presented a satisfactory result since they could understand the objects in different perspectives, using the skills according to the conceptions defended by Gutiérrez (1996), as perception of spatial position, visual discrimination, figure-background perception, perceptive constancy and mental rotation.

After the use of Sólidos RA application, it was possible to see that the totality of students recognized the presented geometrical solids and classified correctly the vertices, edges and faces of each object.

In the activity proposed after the application of the visualization module, indicated in figure 6, students presented the right answers and were able to associate correctly the figures of the pyramid and hexagonal prism.

In the answers about resemblances between the pentagonal prism and pyramid the students presented the following answers:

Student A: Both solids have hexagonal bases.

Student B: Both solids have hexagonal bases.

Student C: The base of the pyramid and prism have six edges.

Student D: Both pentagonal prism and pyramid have five lateral faces.

Regarding the **differences** between prism and pyramid, the following answers were gathered:

Student A: The prism has two hexagonal bases and the pyramid only one.

Student B: The prism has two bases and the pyramid only one.

Student C: Quantity of bases.

Student D: Quantity of bases and vertices are different.

To Duval (2009), the dimensional deconstruction is omnipresent in all definition, reasoning and explanation regarding figures in geometry. Planify a parallelepiped (tridimensional figure), for example, is to deconstruct it into six rectangles (bidimensional figures) that must have the measures and disposition necessary to build the original one.

Some students committed mistakes while selection the middle option, confusing bases and faces. No student chose the first option that refers to the planification of a parallelepiped.

Therefore, the students presented skill when visually discriminating and comparing resemblances and specific differences in solids, through representation in the form of figures according to the activity proposed in figure 6 and yet, recognized the planification of a geometrical solid according to the activity proposed in figure 7.

Visual discrimination, one of the main skills proposed by Gutierrez (1996), refers to the capacity of comparing several objects, figures and/or mental images to identify resemblances and differences among them. Based on the answers, it is possible to infer that this skill was developed. Besides, the application performed an important role by aiding in the development of visualization skills in the context of spatial geometry.

According to Ausubel's theory, the geometrical concepts worked with the students are the subsumers, while the proposed activities contributed to the amplification and update of the previous knowledge. “Meaningful learning occurs when the new information anchors itself in concepts or prepositions that are relevant and already exist in the cognitive structure of the apprentice” (Moreira, 2019, p. 161).

It was possible to notice that, while students manipulated the geometrical objects and their planification, they stablished relations, noticing resemblances and differences in the figures. With Sólidos RA application, the content learning passed from the level of visualization to more elaborate levels of spatial perception since basic concepts of visualization that demand more abstraction.

CONSIDERATIONS

This research presented evidence that the adoption of Sólidos RA application for exploring and visualizing spatial geometrical solids may contribute to the teaching of spatial geometry.

By observing the manipulation in real time of the spatial object, it was verified that students practice and sharpen ways of discovering and representing with visualization skill and comprehension of geometrical solids and round bodies. Besides, it was observed the aspect of involvement from the students who proposed questions about the theme in each step, even from the one who did not have the habit of manifesting during mathematics classes.

It was possible to identify an important answer in the conception of meaningful learning theory because of the change in the priority of learning construction since students instead of prioritizing memorization started to give more importance to the comprehension of the presented concepts.

In the activities of the creation module, it was observed the development of visualization skills, such as: visual discrimination, perception of spatial position, perceptive constancy, figure-background perception and mental rotation. What corroborates with the ideas proposed by Gutiérrez (1996).

In general terms, the limitations found by the students regarding learning spatial geometry concepts, before the insertion of AR were solved after the use of the application, confirming the perception that its use proposes the teaching geometry with AR in an interactive, dynamic and experimental form. According to Ausubel (2003, p. 2) “human beings interpret perceptual experiences ‘em bruto’ in terms of specific concepts in their cognitive structures”.

This result meets the model of meaningful reception learning of Ausubel (2003), that proposes new meanings arise during learning when students have access to the same concept presented in a material potentially significant (Ausubel, 2003).

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It is important to highlight that students recognize geometrical solids from their characteristics, that were presented in previous classes before the use of the class presented in this article. This is another relevant factor in the meaningful learning theory since, according to Ausubel (2003), learning happens when the student feels capable of relating a new content with their previous knowledge.

It was also verified that the use of Sólidos RA application has potential to contribute to the teaching practice for being a supporting tool and providing a different manner to teach spatial geometry, inserting diversified approaches in classes. In this sense, the teaching of geometry supported by the use of Sólidos RA application may provide a different model to build knowledge.

It is possible to observe that the use of visualization module contributed for the development of the following skills: visual discrimination, figure-background perception and perceptive constancy. Thus, the explored pedagogical strategy made possible to answer the question from this research because Sólidos RA application contributed with the organization of geometrical thinking and development of visualization skills by the students.

As proposal for future studier, we suggest the performance of other practices that involved the use of AR in mathematics education. It is expected that such practices may contribute to the teaching of other mathematical curricular components, such as the teaching of functions, collaborating continuously with the processes of learning and teaching in mathematics.

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