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Artificial intelligence in teaching Spatial Geometry

Educational resources and digital culture for Elementary Education

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Abstract: The article investigates the impact of Artificial Intelligence (AI) on the teaching of spatial geometry through an educational game, implemented in a public school in northern Brazil for primary education in the first and last years. Using a qualitative-quantitative approach and action research, questionnaires and observations were used to evaluate the game in promoting meaningful learning and digital inclusion. The results show that AI can be successfully adapted to educational environments, contributing to students' interest and motivation, and supporting the teacher in facilitating learning related to students' daily lives.

Keywords: Basic Education; Game; Neural Networks.

Inteligência Artificial no Ensino de Geometria Espacial: Recursos educacionais e cultura digital para o Ensino Fundamental

Resumo: O artigo investiga o impacto da Inteligência Artificial (IA) no ensino de geometria espacial por meio de um jogo educativo, implementado em uma escola pública do Norte do Brasil para o ensino fundamental nos anos iniciais e finais. Utilizando uma abordagem quali-

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quantitativa e pesquisa-ação, foram aplicados questionários e observações para avaliar o jogo na promoção de aprendizagem significativa e inclusão digital. Os resultados indicam que a IA pode ser adaptada com sucesso para ambientes educacionais e contribui para o interesse e a motivação dos alunos e ao apoiar o professor na facilitação do aprendizado conectado ao cotidiano dos estudantes.

Palavras-chave: Ensino Básico; Jogo; Redes Neurais.

La inteligencia artificial en la enseñanza de la geometría espacial: Recursos educativos y cultura digital para la enseñanza primaria

Resumen: El artículo investiga el impacto de la inteligencia artificial (IA) en la enseñanza de la geometría espacial a través de un juego educativo implementado en una escuela pública del norte de Brasil para la enseñanza primaria en los cursos inicial y final. Para evaluar el juego en la promoción del aprendizaje significativo y la inclusión digital, se aplicaron cuestionarios y observaciones mediante un enfoque cualitativo-cuantitativo y la investigación-acción. Los resultados indican que la IA puede adaptarse con éxito a entornos educativos, contribuye al interés y la motivación de los alumnos y ayuda al profesor a facilitar un aprendizaje conectado con la vida cotidiana de los estudiantes.

Palabras clave: Educación Básica; Juego; Redes Neuronales

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1 INTRODUCTION

In the current educational context, the introduction of digital information and communication technologies (DICT) and artificial intelligence (AI), such as neural networks, enables new forms of personalization and engagement. As pointed out by Ludermir (2021), AI can revolutionize teaching by increasing student engagement and adapting to individual needs, thus configuring itself as a strategic educational resource in contemporary digital culture.

Digital culture has changed students' relationship with knowledge, providing access to multimodal resources that expand the understanding and meaning of content. Studies show that educational games supported by neural networks not only reinforce concepts but also develop basic cognitive skills in an environment familiar to students (Unesco, 2014).

Mathematics is a fundamental part of the curriculum for children and adolescents. Its importance is justified by its application in the job market, its use as a basis for other areas of knowledge, and, more generally, in the construction of citizenship, as society increasingly seeks to improve and achieve new scientific knowledge and technological resources.

However, when it comes to teaching this curricular component, it is noted that it causes negative feelings for those who teach and those who study. According to the National Curricular Parameters for Mathematics (PCNs), on the one hand, there is the realization that this is an important area of knowledge, and on the other hand, there is dissatisfaction with the negative results obtained concerning its learning (Santos, 2014).

These adversities show that there are problems to be faced in the teaching and learning process. It is necessary to reverse the teaching that focuses on mechanical learning without meaning for the student, in addition to reviewing and reformulating content and methodologies that are compatible with the current profile of students, in a technological era, and that promote improvements in the teaching-learning process.

For Orange et al. (2018), there are many discussions about improvements and teaching alternatives that provide significant learning, but there is still a notable fear of applying new teaching solutions, as well as a lack of resources to work with new practices.

An important factor that influences learning is what the individual already knows, for example, significant learning requires expanding and shaping ideas that already exist in the

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mental structure so that the individual is able to relate and access new content (Ausubel, 2003).

According to Moran, Masseto and Behrens (2013), with technologies, schools can become spaces rich in meaningful learning that motivate students to be active learners, to constantly explore, to be proactive, to interact, and to know how to take initiative.

Digital technologies have helped in the search for solutions to improve the teaching-learning process. Currently, there is a range of digital information and communication technologies (DICTs) aimed at the most diverse areas of teaching, such as games, applications, and virtual learning environments, virtual reality, as well as the possibilities of new methodologies based on products/resources of computational thinking, robotics, and artificial intelligence.

According to Costa and Prado (2015), DICTs provide a variety of knowledge that is essential for mathematics teachers to be able to "create with", and "teach with" technology. However, teaching is not limited to the incorporation of DICTs in the classroom but to the integration and exploration of what they can improve for the teaching and learning mathematics.

In this sense, regarding current technologies, there are today several Artificial Intelligence (AI) techniques and algorithms, such as Artificial Neural Networks (ANN), in the development of games and applications capable of recognizing, learning, and adapting. These applications, as well as the field of study of AI itself, have gained space in education in the form of subject and content support and distance education classes on specialized platforms with content provided by mathematics teachers (Badin; Bordignon; Agosti, 2017).

For education, in recent years, AI has shown its relevance in the study of several fields of knowledge, allowing the development of studies, software, and games, among other applications aimed at teaching and problem-solving. Another point is that part of the relevance of AI for education is in the development of technologies that allow the inclusion of people with disabilities and adaptability to different learning styles.

In light of these considerations, this article aims to report the development of an educational technical product (ETP) developed during the Master's degree of the first author, under the guidance of the other authors, related to AI and possible contributions to the process of teaching spatial geometry in the first and last years of elementary school in a school in the

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North Region of Brazil.

2 GAME GeometrIA

The GeometrIA game uses a convolutional neural network to promote meaningful learning by considering and adapting to student responses, as proposed by Ludermir (2021) and Fernandes-Sobrinho and Fernandes (2024). This structure contributes to the digital culture in education by enabling an interactive and adaptive experience, which is essential for engagement in learning complex geometries.

It is important to emphasize that there are several types of Artificial Neural Networks (ANN); however, this product uses a Convolutional Neural Network, (CNN)". According to Taulli (2020, p. 119, translated by us), "A convolutional neural network (CNN) analyzes data section by section (that is, by convolutions). This model is targeted at complex applications such as image recognition."

The idea to build this EPT came from an informal conversation with math teachers at a city school about teaching geometry, that was difficult for students to recognize geometric shapes precisely because there was no contextualization with everyday life, and this difficulty led to other difficulties and even a lack of interest in learning geometry.

Soon, one of the teachers suggested using technology to help students recognize these geometric shapes, especially geometric solids, in their everyday lives. This conversation took place during the pandemic, when teaching was still remote, which also led to observations and perceptions about the difficulties of learning mathematics.

According to Marques and Caldeira (2018), one of the possibilities to make classes more attractive to students is to propose to elementary school mathematics teachers the use of technologies and methodological approaches that facilitate the visualization and connection of geometry content with students' daily lives.

The purpose of the GeometrIA game is to draw geometric solids and have the student identify in the real world the largest number of objects that have the shape of the drawn geometric solid. The Artificial Neural Network (ANN), on the other hand, will try to identify the object shown by the student and will score points every time it recognizes it and is within

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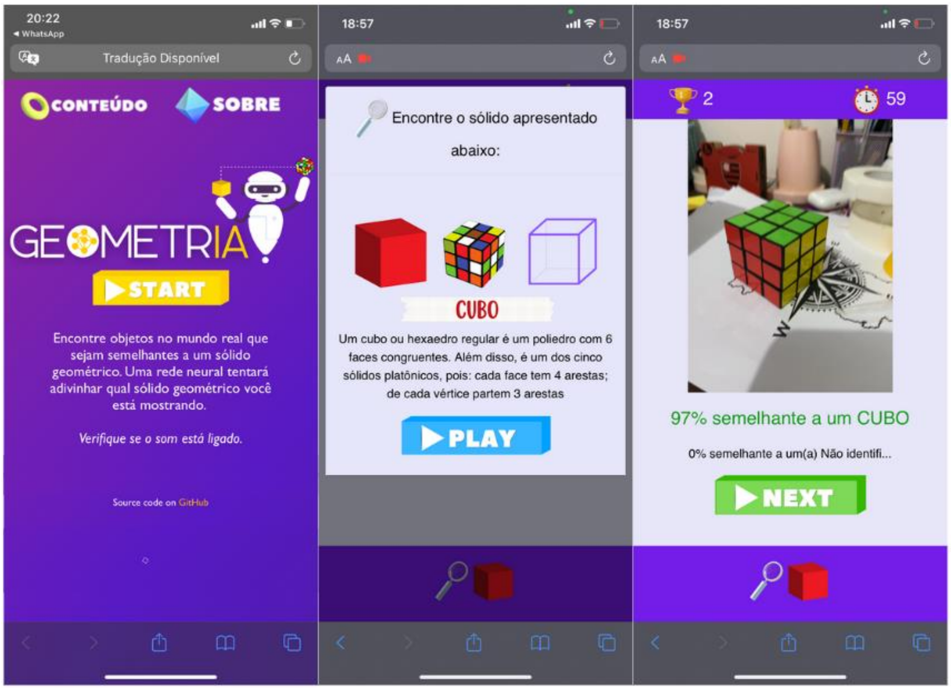
the time set in the game, as shown in Figure 1.

The student wins based on the highest score he/she achieves and loses each time he/she fails to identify the geometric solid, returning to the review content and a new attempt at the game. The following subsections aim to explain a bit about the development process of the Geometria game, highlighting the tools used and the training of the Artificial Neural Network (ANN).

Figure 1 – GeometrIA Game Screens



Source: Authors (2022).

The game structure was built by training a Convolutional ANN composed of a dataset of 3,500 color (RGB) images with dimensions of 224 x 224 pixels, obtained from everyday objects with the shape of a geometric solid. The images used in the ANN were classified into eight classes: cylinder, cone, cube, sphere, parallelepiped, quadrangular pyramid, triangular prism, and "unidentified". Each class has the same number of images with the same dimension.

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The ANN was trained with 200 epochs, a batch size of 32, and a learning rate of 0.001. After training, the platform provides some accuracy data by class, epoch, and confusion matrix on the trained model, which are useful to perform new tests to improve the performance of the ANN. Therefore, the definition of the model to be used in GeometrIA was based on accuracy and the absence of overfitting.

Regarding the information provided, we have: batch size refers to the number of samples processed by the model before updating its parameters. In this case, a batch size of 32 means that the model processes 32 images at a time before adjusting its weights. The learning rate is a parameter that determines the size of the adjustments made to the model's weights at each iteration. A rate of 0.001 indicates that the adjustments will be small, promoting gradual learning.

Class Accuracy assesses the accuracy of the model for each class individually, helping to understand how it behaves with different types of objects. An epoch corresponds to a complete pass through the dataset during training, and the model was trained for 200 epochs to improve its performance. The confusion matrix is a table that compares the model's predictions with the actual values, detailing the hits and misses for each class, and providing a detailed view of the model's performance.

Thus, Figure 1 shows that the model used classified 75 samples, obtaining accuracy per class between 0.92 and 1 (92 to 100%). A model's prediction is perfect when the accuracy is equivalent to 1.00 (if you prefer Figure 2) or 1.0 (if you prefer Figure 3), and imperfect when it has values lower than one (1.00 or 1.0).

Figure 2 - Accuracy by class

CLASS	ACCURACY	# SAMPLES
Cilindro	0.97	75
Cone	0.92	75
Cubo	1.00	75
Esfera	1.00	75
Paralelepípedo	0.93	75
Pirâmide	0.96	75
Prisma	0.96	75

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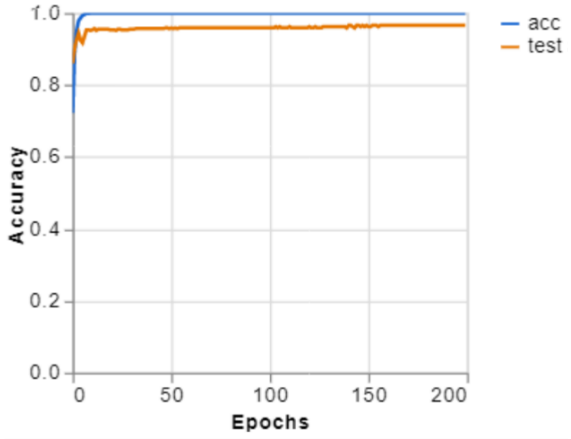
Source: Authors (2023).

Figure 3 - Accuracy by period



Source : Authors (2023).

The results in Figure 2 show the accuracy per epoch, which allows us to see if the model is overfit or not. In this case, the model can classify other objects that are different from those used in training and is, therefore, more dynamic. This aspect is important for the application since many of the objects the players will encounter will not be perfect geometric solids but will have a similar shape. Therefore, the trained model meets the gameplay requirements of the application.

It is important to note that 85% of the samples were used to train the model to correctly classify the samples into the created classes. The other 15% of samples are used for testing to verify how well the model performs on new, never-before-seen data. These parameters are defined by the Teachable Machine platform itself and cannot be changed.

After training and testing, the neural network was exported to develop the game structure using the JavaScript programming language. After structuring, an interactive web interface was developed using HTML5 (HyperText Markup Language) Canva resources, along with other JavaScript and CSS (Cascade Style Sheet) language resources, to make the game more attractive and usable for students and teachers during math class and at other times outside of the school environment.

The Geometry content was implemented in the game in two ways: basic and direct concept and general explanatory concept. The basic concepts were applied in the application's gameplay and interaction with the AI, as shown in Figure 4 (Screen A).

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Figure 4 – Geometry contents presented in the game

Source: Authors (2022).

These basic concepts are necessary to facilitate memorization and acquisition of new concepts based on the assimilation of the object found in everyday life with the figures represented in textbooks and other Geometry content.

HTML pages with general explanatory concepts about what flat and non-flat figures, what geometric solids, polyhedrons, spheres, and others, have also been implemented in the game. This content, as shown in Figure 4 (Screen B and C), is intended to provide a review of the content since if the student is unable to identify a geometric solid, the game will indicate a review of the content and a new attempt.

Along with the content, some regional and local curiosities are also presented in Figure 4 (Screen D), with the purpose of strengthening the relationship between the content and the knowledge schemes present in the students' cognitive structure since these are places that these students already know and can visualize.

Another point is that geometry is part of our daily lives, from toys to buildings. By playing and exploring the world, children naturally develop a geometric sense and learn about shapes, sizes, and spaces (Fonseca et al., 2009).

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3 METHODOLOGICAL PATH

The research was conducted with four teachers from a municipal elementary school located in the northern region of Brazil. For the data collection, a questionnaire was developed by the researcher on the platform Google Forms. The questionnaire used had 20 questions, however, in this report, only four questions dealt with the technical aspects of EPT. The questions were scored according to the degree of agreement or disagreement on a five-point Likert scale.

The population of this study consisted of tenured and hired teachers working in elementary education in the school unit where the research was conducted. The sample included four teachers: two educators who teach mathematics in the early years and two mathematics teachers in the last years of elementary school. The choice of this sample is justified by the approach of the content of spatial geometry, which is worked on in both stages of elementary school.

In addition to the quantitative and qualitative analysis, this study considered the ethical aspects of using AI in the educational environment. The data collection follows the principles of privacy and transparency as recommended by Fernandes-Sobrinho (2023) and the European Union, in addition to having been approved by the Research Ethics Committee according to Opinion No. 5.337.993/2022. This perspective seeks to balance pedagogical innovation with due respect for the fundamental rights of students.

The analysis of the questionnaire was carried out through content analysis. For Bardin (2011), content analysis is a method that uses various techniques to examine messages, such as texts or images. Its main objective is to identify and quantify the frequency of certain words, phrases, and ideas to gain a deeper understanding of the content.

In other words, Fernandes-Sobrinho (2016) explains that this method consists of a set of techniques used in data processing and analysis. The author also adds that the method processes information based on a script divided into three phases: a) pre-analysis; b) exploration of the material; and c) processing of the results.

In this study, we followed the same script. In phase (a) we started to organize the

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questionnaire into a corpus. Phase (b) consisted of the exploration of the material and the extraction and coding of the results obtained. To do this, we used eight of the 20 questions in the questionnaire, which were a priori condensed into discussion indicators and categories.

In this work, the categories were previously defined and adapted from the electronic games evaluation tool by Vilarinho and Leite (2015). Thus, the results obtained were classified into two dimensions: "pedagogical" and "interface". In phase (c), the results were processed, derived, and interpreted using simple statistical operations.

To facilitate the visualization of the data obtained, the graphs presented below were organized using the indicators established in phase (b), instead of the questions themselves.

4 RESULTS

In this section, we will present the results obtained through the collection and content analysis of the data with discussions about the contributions of the game GeometrIA in the teaching of geometric solids. For a better understanding of the results obtained, we have structured the arguments in three subsections according to the categories used in the material exploration phase in the content analysis of the data.

For Moreira and Masini (2006), the teacher's role in facilitating meaningful learning involves four fundamental tasks, which, in a summarized form, are: a) Task One - Identifying the conceptual and propositional structure of the teaching material; b) Task Two - Identifying the subsumers relevant to learning the content to be taught; c) Task Three - Diagnosing what the student already knows; d) Task Four - Teaching based on resources and principles that facilitate the acquisition of concepts in a meaningful way.

In this context, the pedagogical dimension brings together questions aimed at understanding how the GeometrIA Game contributes to achieving these tasks, as well as verifying whether the game meets the necessary conditions established by Ausubel (2003) for meaningful learning.

Graph 1 presents indicators that are appropriate for the substantive way in which content is presented to students. It can be seen that four participants in the research answered that they "completely agree" when asked about the indicators of "appropriateness of language", "clarity of objectives" and "correctness of content" presented in the game.

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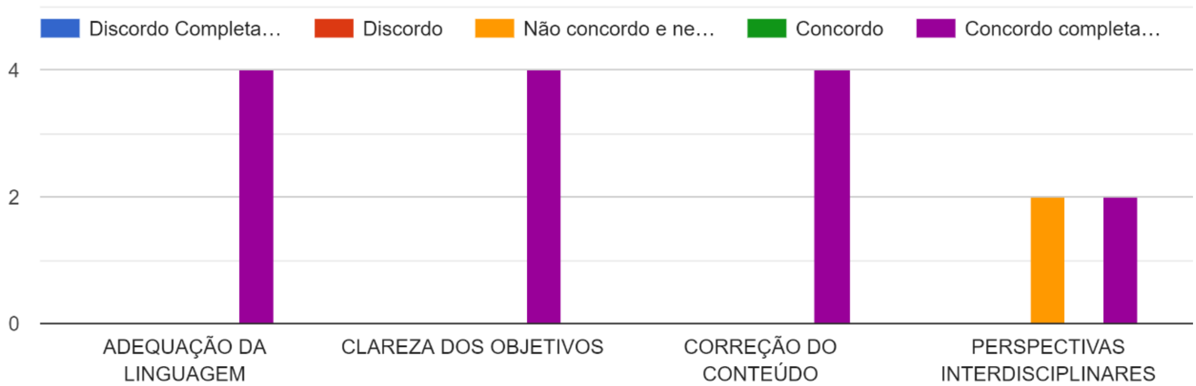
Graph 1 - Pedagogical dimension A



Source: Authors (2022).

Regarding the indicator "Interdisciplinary perspective", the researchers were asked whether the game presented problem situations that offered an interdisciplinary perspective, mobilizing concepts from different fields of knowledge in an articulated way. Two participants were neutral, neither agreeing nor disagreeing with the question. The other teachers answered, "I strongly agree".

The results obtained from Graph 1 converge with what Moreira and Masini (2006) emphasized in the first task, since the use of appropriate language, clarity of objectives, and interdisciplinarity favored the presentation of unified and inclusive concepts, with an enlightening potential and characteristics that facilitate assimilation.

The correction of content, when presented in an organized and sequential manner, complements the didactic proposal of Task 1 and facilitates student understanding. Ausubel's theory emphasizes the importance of identifying and structuring basic concepts for meaningful learning, especially in a field like geometry that requires precise mental organization.

Clarity of objectives is also in line with the proposal of task two, since to identify subsumers it is necessary to look for clear, precise, and stable concepts, propositions, and ideas that are relevant to the content to be taught, taking into account what the student already knows (Moreira; Masini, 2006).

Task three requires the teacher to diagnose what the student already knows by

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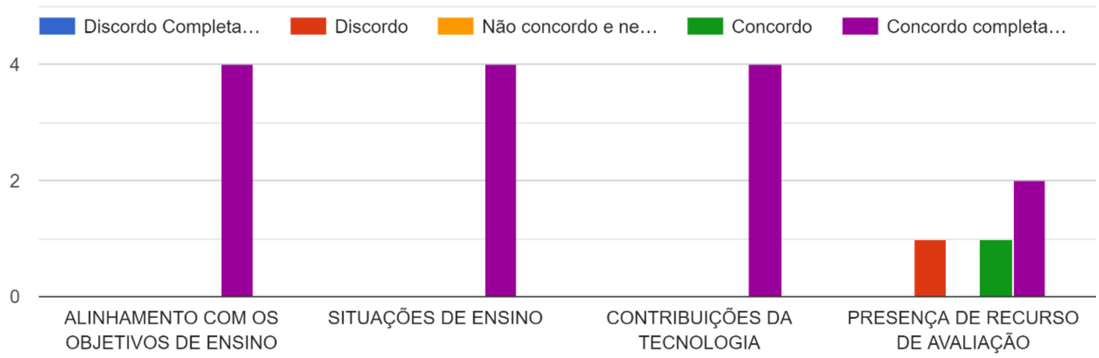
determining which of the relevant subsumers are available in the student's cognitive structure. In this way, the interdisciplinary organization of content enhances learning by integrating concepts from different domains.

According to Moran and Bacich (2018), teachers need to discover the motivations of each student, what motivates them to learn, and the most appropriate pathways, techniques, and technologies for each situation.

Moving forward, Graph 2 presents indicators related to the principles and resources that facilitate the presentation of content and appropriate planning for the sequential organization of the discipline. In this sense, the indicator "Alignment with teaching objectives" aimed to ask whether the game is aligned with the teaching objectives of the curricular proposal of the discipline. All participants answered, "I completely agree". The indicator "Teaching situations" refers to the use of the Geometria game by teachers in situations such as guided study, remote activities, extracurricular activities, dynamics, and others. All four research participants answered, "I strongly agree", that is, they used the game in their teaching practice.

The results show that the GeometrIA game has significant potential and achieves what is proposed in Task Four, as it is a technological resource that facilitates the acquisition of basic geometry concepts through content organized sequentially in a meaningful way.

Graph 2 - Pedagogical dimension B



Source: Authors (2022).

Thus, when teaching with appropriate principles and resources, whether technological

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or not, the teacher's role becomes one of helping the student to assimilate the subject being worked on and to organize their cognitive structure in this area of knowledge through the acquisition of clear and concise meanings (Moreira; Masini, 2006).

Regarding the "Contributions of technology" indicator, the question was whether the artificial intelligence used in the game could contribute to a better understanding of the geometry subject to be taught. All four respondents answered, "I strongly agree".

Given this result, it is worth adding that as AI becomes an increasingly common technology in people's daily lives, it will become more intelligent. Consequently, the more insightful it is, the more people will use it, providing learning and helping modern people in their learning and training (Fava, 2018).

However, the use of a technological resource alone does not guarantee the quality of teaching, so there must be an interaction between teacher and student in the choice of skills and methodologies with the support of technological resources so that the teaching-learning process occurs in a significant, efficient, effective and effective way.

In this sense, it is clearly understood that digital technologies must serve as a facilitating element that simplifies understanding in the most diverse areas, creating conditions for students to assimilate knowledge still under construction with others already known and of interest to them, using technology (Verastzo; Baião; Sousa, 2019).

Regarding the "presence of assessment resources", it was asked about the presence of assessment resources through exercises or problem situations. The responses obtained showed disagreement from one participant and agreement from three.

Although only one participant disagreed with the presence of an assessment resource, the GeometrIA game does not explicitly offer this resource, because the proposal of the game is based on the effort to present content that is related to pre-existing knowledge in the student's cognitive structure. Thus, the assessment methods depend on the teacher's objectives and planning when using this technology.

However, to do this, today's professionals need to develop their computational thinking and keep abreast of technological innovations. This does not necessarily mean acquiring knowledge to develop software and applications, but knowing how to use technology, understanding the process behind it to obtain information, making a decision based on data, and

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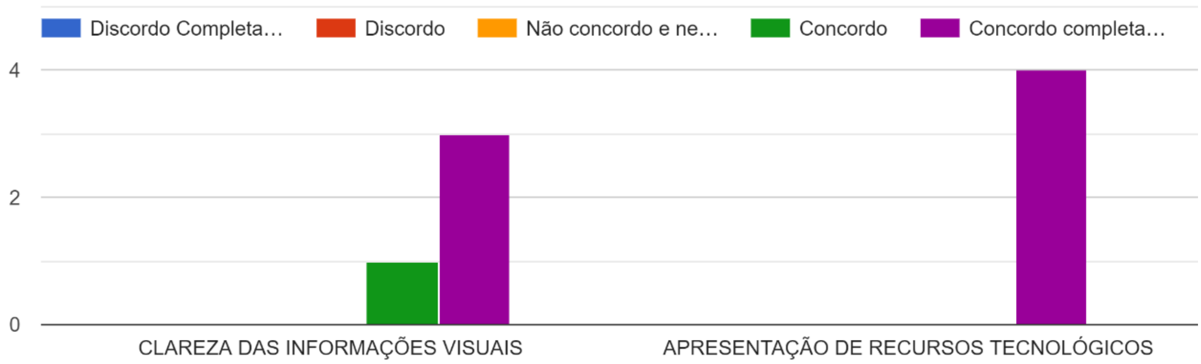
knowing how to deal with different lines of reasoning (Fava, 2018).

In the interface dimension, we tried to evaluate the visual characteristics of the game and the presentation of the technology as a differentiating aspect in terms of navigability. Therefore, in the "Clarity of visual information" indicator, shown in Graph 3, we asked whether the game had a clear visual presentation, with the use of fonts, images, colors, and an adequate amount of information per screen. The results show a high level of agreement among the participants regarding the clarity of visual information.

Graph 3 - Interface dimension



Source: Authors (2022).

In this sense, geometric knowledge in the first years of elementary school allows the creation of representations that are easily interpreted in visual resources for different concepts related to such content (Fonseca et al., 2009).

The GeometrIA game interface is simple, educational, colorful, and illustrated to facilitate the presentation and assimilation of the content. According to Perry et al. (2007), there are some principles of Ausubel's theory that serve as guidelines for the elaboration of the general objectives and scope of a game, such as the search for strategies for presenting the content associated with interactive challenges and safe guidelines for accessing audiovisual stimuli that motivate and maintain the focus of the student's activity towards the search for learning.

In the "Presentation of technological resources" indicator, the question was whether the artificial intelligence used was a differentiator for the game. All four respondents answered, "I

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strongly agree". In line with this result, Fava (2018) argues that AI is no longer a science fiction dream, but has become real, being installed in smartphones and able to help its owner make decisions.

Therefore, it is essential to pay attention to an educational model that follows the trends, in addition to preparing teachers to be open to new technologies that offer different types of communication and interaction.

Mobile applications that present content in a diversified, personalized, and interactive way, other technologies such as CD, DVD, TV, and even the famous presentation programs completely focused on content have become somewhat outdated and are increasingly being used in the current educational scenario.

5 CONSIDERATIONS

Understanding that the use of digital technologies is necessary for more meaningful learning, due to accessibility, portability, interactivity, and proximity to the current reality of students, the game GeometrIA was developed, which uses a trained machine learning model to identify geometric solids with an accuracy ranging from 92 to 100%.

GeometrIA, in its first version published in this paper, still shows its limitations in terms of interaction, personalization, and assessment. However, we are trying to personalize the teaching according to the student's needs through technological capabilities and advances.

However, the goal of its implementation, based on Ausubel's view of meaningful learning, was to contribute to the teaching of geometric solids at the elementary level of basic education. It was possible to understand that the game GeometrIA meets the necessary conditions for meaningful learning since it is a digital tool with significant potential and can assist the teacher in facilitating knowledge construction through visual content related to the students' everyday life.

This statement is justified based on the results obtained in the research, since all participating teachers, when asked, fully agreed with the game's ability to motivate and create more willingness to learn geometry subjects. They also agreed on other aspects of the game such as "appropriateness of language", "clarity of objectives" and "correctness of content", which also contribute to the effectiveness of the teacher's role in

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facilitating meaningful learning.

Another positive point revealed in the research results was the good acceptance of the game by the teachers, as they all fully agreed when asked whether they would use GeometrIA in teaching situations such as guided study, remote activities, extracurricular activities, dynamics, and others.

The results indicate that AI can transform teaching by facilitating personalization and real-time monitoring of students' difficulties. It can be seen that the application of Geometry resulted in greater learning of concepts, student engagement, and motivation, reinforcing the role of digital resources as enhancers of meaningful learning.

As future work, we intend to improve the neural network using an image skeletonization technique to extract the representation of the topology of the geometric solid, and thus perform new training to improve the recognition of the solid and enable better interaction with the user. The research results suggest that the implementation of AI in educational resources should expand beyond games to include personalized learning platforms and virtual assistants. This would enable continuous and adaptive learning, which is crucial for the development of competencies in line with the Sustainable Development Goal (SDG 4) and the demands of modern digital culture.

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