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Educação Matemática Debate

Stimulating epistemological curiosity through investigative activities in Geometry with educational robotics

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Article

Abstract: This article aims to discuss the stimulation of Epistemological Curiosity through Investigative Activities in Geometry with Educational Robotics in Middle School. The work is theoretically based on Mathematical Investigations and address students' curiosity in the relationship between Geometry, Digital Technologies and Educational Robotics. In the study carried out, we opted for qualitative research methodology, as it prioritizes data collection in a personal and interpretative way. The research results reveal that Educational Robotics, when incorporated as a pedagogical tool, provided students with a rich and innovative experience, distinct from traditional approaches, developing geometric knowledge through meaningful learning and contributing to the development of epistemological curiosity.

Keywords: Educational Robotics. Mathematical Investigations. Mathematics Education. Digital Technologies. Middle School.

Estimular la curiosidad epistemológica a través de actividades de investigación en Geometría con robótica educativa

Resumen: Este artículo tiene como objetivo discutir la estimulación de la curiosidad epistemológica a través de Actividades de Investigación en Geometría con Robótica Educativa en la Educación Secundaría. El trabajo se fundamenta en Investigaciones Matemáticas y aborda la curiosidad de los estudiantes en la relación entre Geometría, Tecnologías Digitales y Robótica Educativa. Se optó por la metodología de investigación cualitativa, ya que prioriza la recogida de datos de forma personal e interpretativa. Los resultados de la investigación revelan que la Robótica Educativa, cuando se incorpora como herramienta pedagógica, brindó a los estudiantes una experiencia rica e innovadora, distinta de los tradicionales, desarrollando conocimientos geométricos a través del aprendizaje significativo y contribuyendo al desarrollo de la curiosidad epistemológica.

Palabras clave: Robótica Educativa. Investigaciones Matemáticas. Educación Matemática. Tecnologías Digitales. Educación Secundaría.

Estimulando a curiosidade epistemológica por meio de atividades investigativas em Geometria com robótica educacional

Resumo: O estudo objetivou discutir o estímulo à curiosidade epistemológica por meio de Atividades Investigativas em Geometria com Robótica Educacional nos Anos Finais do Ensino Fundamental. O trabalho é teoricamente embasado nas Investigações Matemáticas e aborda a curiosidade dos alunos na relação entre a Geometria, as Tecnologias Digitais e a Robótica Educacional. No estudo realizado, optou-se pela metodologia de pesquisa qualitativa, pois ela prioriza a coleta de dados de forma pessoal e interpretativa. Os resultados da pesquisa revelaram que a Robótica Educacional, ao ser incorporada como ferramenta pedagógica, proporcionou aos alunos uma experiência rica e inovadora, distinta das abordagens tradicionais, desenvolvendo o conhecimento geométrico por meio de uma aprendizagem significativa e colaborando para o desenvolvimento da curiosidade epistemológica.

Palavras-chave: Robótica Educacional. Investigações Matemáticas. Educação Matemática. Tecnologias Digitais. Ensino Fundamental.

1 Introduction

The song *Geni e o Zepelim*[1], by Francisco Buarque de Holanda, popularly known as Chico Buarque (1978), was a social critique in the 1970s, a period in which marginalized society was often discriminated against. The character Geni is portrayed as a prostitute, the target of ridicule by the locals.

On the other hand, the Zepelim represents a dirigible aircraft, whose commander threatens to destroy the city. However, this same commander offered the following alternative to stop his fury: Geni would have to agree to sleep with him. At this moment, society, which previously despised her, now depends on her to survive.

Begged by the same members of society who had previously despised her, Geni gives in and agrees to be the commander's lover. Satisfied, the commander bids farewell to the city, which remains saved thanks to Geni's generosity. However, as soon as the Zeppelin disappeared into the sky, society resumed its usual routine, imbued with even more hostility, as noted at the end of the song: “Throw stones at Geni! Throw shit at Geni! She's made to be beaten! She's good at spitting! She'll give it to anyone! Damn Geni!”.

Inspired by this song, Borba, Souto and Canedo-Junior (2023) propose a reflection that relates the story portrayed in *Geni and the Zeppelin* with what happened with Digital Technologies during the pandemic period caused by Covid-19, in a context of Mathematics Education. During this period, Digital Technologies served as support for many educational institutions in a context in which isolation was necessary. The school environment that was previously in-person began to take place completely remotely due to the need for social distancing from 2020 onwards. In this scenario, WhatsApp groups and platforms such as Google Forms, Google Meet, Zoom, among others, were crucial to ensuring the continuity of learning for many students.

As indicated by Borba, Souto and Canedo-Junior (2022), no previously developed program was able to influence the integration of Digital Technologies in Mathematics Education as much as the Covid-19 pandemic. The advent of the virus caused considerable impacts, since the proposed reforms, which included and prioritized Digital Technologies, seemed to have failed to integrate them significantly into Mathematics Education (Borba, Souto and Canedo-Junior, 2022). This reflection refers to the metaphor of Zeppelin and Geni, in which Digital Technologies played an important role in the studies of many students, especially in a scenario in which face-to-face teaching was unfeasible.

Currently, in a post-pandemic context, with face-to-face classes resumed since 2022, these technologies have been little used in classrooms. Despite having proven essential for the continuity of education during the pandemic, with the return to in-person learning, many schools have not integrated digital tools into their daily school routine. In addition, many students, teachers, and even parents and guardians have begun to show fatigue and dissatisfaction with the use of technology in the school context.

This feeling can be explained by several factors, such as the lack of access to Digital Technologies, digital overload, the difficulty in adapting to new platforms, the lack of adequate training for the effective use of these tools, and the need for face-to-face interactions, especially for children and adolescents. In addition, the lack of an appropriate study environment at home, such as a quiet and comfortable space, further compromised the learning process.

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[1] BUARQUE, Chico. *Geni e o Zepelim*. Album: Opera do Malandro. Rio de Janeiro: Philips Discos, 1978.

Even if one agrees with the need for universal access to Digital Technologies with good internet connections and the richness of face-to-face meetings, it is considered that this aversion may represent a setback. This is affirmed when taking into account the numerous advantages that Digital Technologies offer for education, such as the personalization of learning, access to vast educational resources, and the preparation of students for an increasingly technological future (Maltempi and Mendes, 2016; Faria and Maltempi, 2020).

Therefore, it is essential to find a balance in which technologies are integrated effectively and sustainably, enriching the educational process without creating overload. It is crucial that educational institutions recognize the value of technologies and seek strategies to integrate them continuously into the school environment. In this context, one of the alternatives that can be explored as a pedagogical proposal is Educational Robotics, which, according to Souza and Castro (2022), provides educational and scientific gains for the teaching of Mathematics. Among the possibilities for strengthening this science and Digital Technologies, Robotics is focused on as a means of overcoming difficulties in learning mathematics.

Thus, this qualitative research aims to discuss the stimulation of curiosity through Investigative Activities in Geometry with Educational Robotics in Middle School. The aim is to contribute to a future in which all Brazilian students have the opportunity to access quality education, which promotes critical citizenship formation aligned with the realities in which they live, regardless of the educational network.

2 Mathematical investigations

Throughout their school career, students are often exposed to memorizing rules and techniques, especially in Mathematics classes (Faria and Maltempi, 2020). In this scenario, other educational strategies that counter this practice are rarely or not even used. Exercises predominate, since traditional methodologies are used under the belief that the more students practice, the more they learn. As noted by Faria and Maltempi (2020), the memorization process in the school environment is limited to memorizing formulas and models of mathematical content without, however, ensuring effective understanding by students.

Encouraging students to think critically and be creative people are some of the educational objectives found in national curricular programs, as well as in international documents (WEF, 2020; Brasil, 2017). According to Freire (1996), teaching must be understood as more than transferring knowledge. This implies that students themselves, with the mediation of teachers, must develop their reasoning and build their knowledge. In this sense, traditional classes, centered on memorization as a fundamental process of the education system, are insufficient to achieve these objectives.

The relevance of the educator's role then becomes clear. For teachers to be considered for peace, they must be certain that their teaching task is not restricted to teaching content; it also involves teaching students how to think correctly, stimulating their curiosity (Freire, 1996). In this way, seeking to instigate students and contribute to their active participation in the learning process, the Mathematical Investigations approach is adopted. According to Rocha and Ponte (2006), this methodology provides students with a new mathematical experience, redefining their understanding.

According to Ponte, Brocardo and Oliveira (2003), investigating is the act of seeking to learn the unknown. Understanding and the ability to solve problems are essential skills for citizens in different areas, since the individual who explores, questions and researches is capable of dealing with the most diverse situations. In this sense, using this skill in the classroom allows students to formulate questions and explanations, transforming the educational environment into a space for investigation and curiosity. According to Skovsmose

(2000, p. 6),

> the invitation is symbolized by the teacher's "What if…?" The students' acceptance of the invitation is symbolized by their "Yes, what if…?" In this way, the students engage in the process of exploration. The teacher's "Why this…?" represents a challenge, and the students' "Yes, why this…?" indicates that they are taking on the challenge and are looking for explanations. When students take ownership of the process of exploration and explanation, the inquiry setting becomes a new learning environment. In the inquiry setting, the students are in charge of the process.

In this format, the teacher, previously seen as the holder of knowledge, assumes the role of mediator, while the student becomes the protagonist of his/her knowledge. Therefore, it is important that there is a relationship between the teacher and the student, since, in this context, communication and participation are relevant for the construction of knowledge. After all, an investigation environment needs to be relational (Skovsmose, 2000).

According to Ponte, Brocardo and Oliveira (2003), Mathematical Investigation develops in three stages, and can be carried out in one or more classes: (i) introduction of the activity proposed by the teacher; (ii) carrying out the investigation individually, in pairs or groups; and (iii) discussion of the results obtained between the students and the teacher. In this way, the school environment arouses curiosity and instigates the spirit of a professional mathematician, since the students are formulating and testing conjectures, discussing and arguing with their peers and the teacher.

Among the possibilities for applying Mathematical Investigations in the school context, Geometry is a rich field, offering countless opportunities for the exploration and discovery of patterns, properties and relationships. Integrating Mathematical Investigations with Geometry can make learning more dynamic and engaging for students.

However, Rocha and Ponte (2006) state that students face difficulties in carrying out these activities, since they are not used to arguing and justifying the results obtained. This occurs because investigative practice differs from traditional classes, which are based on exercises with unique answers generated from standardized models. Thus, "carrying out investigations seems to provide an opportunity for students to use and consolidate their mathematical knowledge, develop their capabilities and carry out new learning" (Rocha and Ponte, 2006, p. 6).

3 Digital Technologies and Educational Robotics

Technological advances in contemporary society have brought significant changes to various aspects of life. According to Kenski (2012), the emergence of new technologies, especially digital ones, has transformed the way society lives, communicates and acts. In the educational context, the use of these innovations allows for transformations in teaching practices, expanding pedagogical possibilities that were previously unfeasible. With Digital Technologies, different approaches to teaching and learning emerge, which become part of people's daily lives (Maltempi and Mendes, 2016; Faria and Maltempi, 2020).

Recognizing the relevance of technologies in the educational context, the Base Nacional Comum Curricular [National Common Curricular Base — BNCC] (Brazil, 2017) recommends the use of Digital Technologies in schools, indicating, in one of its general competencies, that the student be able to

> understand, use and create digital information and communication technologies in a critical, meaningful, reflective and ethical way in different social practices (including

> schools) to communicate, access and disseminate information, produce knowledge, solve problems and exercise protagonism and authorship in personal and collective life (p. 9).

As recommended, a technological tool that stands out for providing *learning by doing* and enables a curious and active learning environment, different from the traditional model, allowing creativity, the organization of ideas and the development of logical reasoning, is Educational Robotics. Understanding this term requires a clear definition of what constitutes a robot and what Robotics is, in order to understand its application in the pedagogical environment.

In the past, according to Matarić (2017), any machine that performed some special mechanical activity was considered a robot. In Europe, during the 17th and 18th centuries, *realistic creatures* were built that could write, play instruments and even *breathe*. Nowadays, these machines would not be classified as robots, since "a robot is an autonomous system that exists in the physical world, can sense its environment and can act on it to achieve some goals" (Matarić, 2017, p. 19). In other words, a robot is an autonomous system, capable of making decisions independently, receiving guidance and instructions without total control from the human being.

Robots exist in the physical world, and are therefore physically present in contemporary society, and are subject to challenges that the cybernetic environment does not provide. Thus, robots restricted to computers are, in fact, considered simulations. A robot perceives the environment through sensors, being able to detect obstacles, sounds, among others. It can interact with the environment, that is, respond to stimuli and move in the world in order to achieve objectives. Therefore, robots have purposes to be achieved that modify, influence and transform society in some way (Matarić, 2017).

In this context, Robotics can be defined as the study of robots, "which means that it is the study of their ability to perceive and act in the physical world autonomously and intentionally" (Matarić, 2017, p. 21). By exploring the principles and concepts of robotics, it is possible to "acquire essential skills and competencies, such as critical thinking, problem solving, collaboration and creativity." (Carneiro and Souza Junior, 2023, p. 3).

Thus, Educational Robotics seeks to employ Robotics in the school environment with the aim of working on the elements of assembly and control of mechanical devices, associating them with curricular content and promoting a process of construction, collaboration, and reconstruction (Silva, 2009). However, the integral construction of robotic devices is very complex.

For this reason, research recommends that, instead of exposing all the processes and concepts of a given task or construction, based on the established objectives and the target audience, teachers should employ the principle of selective exposure. This means hiding more complex details that are not related to the purposes, keeping them in black boxes (Campos, 2017). Therefore, when applied strategically, this invisible and progressively distant world can be observed in Educational Robotics, allowing the gradual opening of these black boxes (Silva and Blikstein, 2020).

4 Epistemological curiosity

Dewey (1959) attributes to curiosity the value of a fundamental factor for the expansion of experience as an essential ingredient for reflective thinking. According to the author, when curiosity manifests itself, it mobilizes the sensory and motor organs in each new contact, which produces a "fervently sought-after wonder" (Dewey, 1959, p. 45) in the object.

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Freire (1996) warns that naive, unarmed, spontaneous curiosity, the kind that makes someone observe the clouds and get lost in the immensity of the blue, is important, since it feeds the desire to know more. However, he emphasizes that, for the researcher, the presence of a methodical, demanding and epistemological curiosity is essential. This curiosity distances oneself from the object of research, allowing one to move away from superficial thinking and approach it with scientific thought, in order to know it deeply and speak about it sensibly. A curiosity that causes restlessness, generates dissatisfaction and triggers the search for knowledge. In the words of Freire (1995),

> it is not spontaneous curiosity that makes it possible to take an epistemological distance. This task falls to epistemological curiosity — by overcoming naive curiosity, it becomes more methodically rigorous. This methodical rigor is what makes the transition from knowledge at the level of common sense to scientific knowledge (p. 78).

This is how the research was conducted, seeking to move the students' spontaneous curiosity towards an epistemological curiosity. The activities were intentionally designed and conducted in a reflective manner, as they involved aspects related to curiosity, provoking "doubt, hesitation, perplexity" (Dewey, 1959, p. 22). These factors move naive curiosity towards the construction of an epistemological curiosity (Faria, 2016).

Thus, stimulating naive curiosity triggers the act of thinking, transforming it into epistemological curiosity, which leads to research, searching, questioning, in the search to clarify the perplexity. According to Faria (2016), curiosity is fundamental for mental associations to be established, contributing to the transformation of naive knowledge, linked to common sense, into epistemological knowledge.

5 Methodology and procedures

Since this is a research project whose objective is to discuss the stimulation of curiosity through Investigative Activities in Geometry with Educational Robotics in Middle School, the qualitative approach proved to be relevant. This type of research aims to explore contexts that are different from traditional ones in order to understand, describe and report specific social events, focusing on data collected in a personal and interpretative manner. Therefore, qualitative research considers the researcher's direct contact with the study context, recognizing it as the safest way to observe, select, analyze and interpret data (Godoy, 1995).

To record this research, activity sheets completed by the students, photographs and a field notebook were used. Seeking a comprehensive interpretation of the contributions of Robotics, all descriptive data, the environment and the students are considered as important elements to be observed and analyzed, not individually, but collectively. When bringing the records of the participating students, it was decided not to disclose their names, in order to protect their identities. Furthermore, it was chosen to analyze only two responses per item of the activity carried out, allowing for the exploration of responses from the same student in different questions, triangulating them with reference authors in the areas of study.

The data presented and discussed in this article come from a final project for a Bachelor's degree in Mathematics, developed concurrently with a scientific initiation research project, carried out by the first author of this article and supervised by the second. To ensure the effectiveness of the research, activities were developed and a lesson plan was drawn up, which structured the implementation of the activities and facilitated the achievement of the teaching objectives that can be accessed in full in the annexes of the final project (Ferreira, 2024).

The activities were developed with ninth-grade students of Middle School, from Escola Estadual Doutor Mariano da Rocha, located in the city of Teixeiras (MG, Brazil), conducted in two face-to-face meetings of two hours each. The activities were carried out in pairs or in trios, in the institution's computer room. The meetings were subdivided into simulations and physical assembly of the materials, called practices. For the simulations, slides were used to guide students in assembling the circuits, allowing them to make the connections simultaneously. In addition, the free web application TinkerCad was used, which allows the creation of 3D projects, circuits, code blocks, among others. The function used in the activities was the code block that makes it possible to observe whether the electronic components respond virtually to the programming, facilitating the real-world connections.

After each simulation, the students performed the practice. The software used to verify and execute the programming was the *Arduino Integrated Development Environment* (IDE). In it, the students copied the code presented in TinkerCad and pasted it into its interface to observe the movement of the components. Thus, in addition to using the computers, projector and protractors provided by the school, some components from the Arduino kit were used: Arduino Uno, potentiometer, servomotor, protoboard, USB type A-B cable and Jumpers.

The research had the collaboration of members of the Digital Technologies Attention Groups (GATE) and the Robotics Specialization Center (NERO), of which the authors are members. The first is coordinated by professors Dr. Silvana Claudia dos Santos (Department of Education) and Dr. Rejane Faria (Department of Mathematics), and the second is coordinated by professor Dr. Alexandre Brandão (Department of Electrical Engineering) of the Federal University of Viçosa. GATE discusses relevant topics related to technology and education, and NERO works with the objective of introducing concepts and applications in the area of Robotics with the goal of training specialized human resources in the areas of control, automation, electronics, information technology and education. These groups have in common the projects *Robotics in Basic Education: Possibilities and Challenges for Teaching and Learning Mathematics, coordinated by the three professors mentioned, and Mathematical Education and Social Robotics: potentialities and challenges in the context of Basic Education*, coordinated by Professor Rejane Faria (Fapemig APQ-04493-23).

It is pertinent to report that, before data collection, the aforementioned research received approval from the Ethics Committee for Research with Human Beings of the Federal University of Viçosa (CAAE 75823323.0.0000.5153).

6 Data analysis

In this section, the implications of Educational Robotics for learning geometric knowledge are analyzed, based on the data collected. Participation and communication were also observed and considered important aspects to provide an educational environment that encourages investigative exploration.

Since the target audience was ninth-grade Middle School students, it is believed that certain processes and concepts should be hidden, kept in *black boxes*, since they go beyond the purpose of the activities (Silva and Blikstein, 2020). In this sense, the programming and its language, as well as some characteristics of the Arduino kit components, were not previously explained during the meetings, in an attempt to pique the students' curiosity.

To perform the simulations, when accessing TinkerCad, the students viewed a home screen that already had the specific programming for that activity, available in the code button in text format. Thus, when making the connections, the students inserted only the ports used and the desired values into the codes. If the ports and connections were correct, the program would be executed. If the program obtained results that were to be presented, these were displayed on the serial monitor.

After this step, the students physically assembled the wire connections as per the project developed in TinkerCad. Then, they copied the programming code and pasted it into the Arduino IDE initial interface. After checking and executing the code in the software, the programming was transferred to the Arduino board via a USB type A-B cable, where it was recorded. Thus, the selected components performed their functions according to the defined commands.

6.1 Understanding the servomotor and potentiometer

In the first meeting, an initial approach was given to Educational Robotics. This introduction was conveyed through slides, providing students with their first contact with the topic in an expository manner. It was observed that, although the students had a general notion of technologies, their perceptions of Robotics were superficial. According to Campos (2017), this suggests that the underlying aspects of Digital Technologies, especially Robotics, remain hidden in black boxes. Thus, this research is considered an opportunity to reveal some of these boxes, encouraging students to explore the context of Robotics in education.

In order to familiarize students with some components of the Arduino kit, three simulations were developed, accompanied by their respective practices. This initial phase, as outlined by Ponte, Brocardo and Oliveira (2003), constitutes an essential stage of an investigative activity, allowing participants to acquire understanding and clarity regarding the subject and the elements to be explored.

In the first simulation, the aim was to get to know the servomotor. To do this, when accessing TinkerCad, students established three connections: ground (black wire), power (red wire) and signal (orange wire). The black wire should be connected to any GND port. The red wire should be connected to the 5V port and the orange wire to any PWM port (~). This configuration was replicated in the physical assembly of the wires (Figure 1).

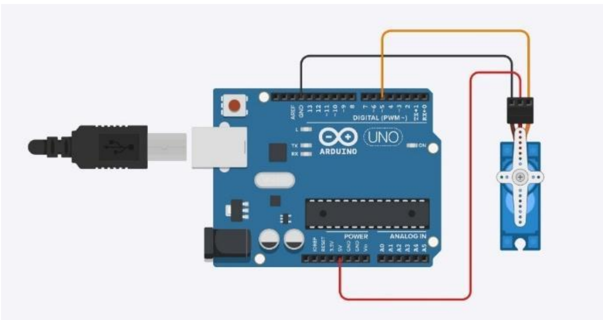

Figure 1: Simulation 1 in TinkerCad (Ferreira, 2023, p. 29)

In this way, students were encouraged to set arbitrary angle values in the programming and observe the servo movement according to their programming. The servomotor used rotates from 0 to 180 degrees and was programmed so that, when a specific angle is set, its propeller moves to that position. For example, when programming an angle of 90º, the servomotor does not perform an additional 90º rotation, but adjusts directly to the 90º position from its current position. One student selected PWM port 5 for the orange wire and an angle of 90º for the servomotor movement, which rotates counterclockwise with an initial angle of 0º (Figure 2).

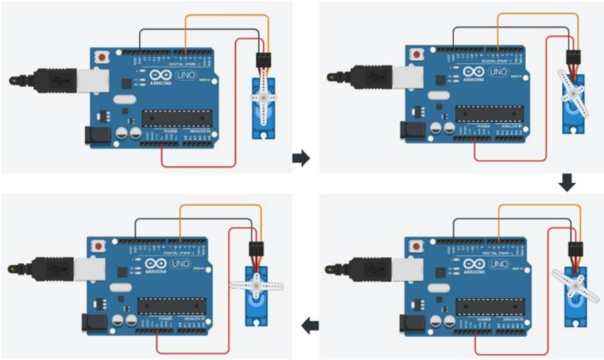

Figure 2: Servomotor movement sequence in TinkerCad (Ferreira, 2023, p. 30)

After making several angle choices, the students proceeded to answer the question shown in Table 1.

Table 1: Getting to know the servomotor

1) The servomotor, a specific type of electric motor, offers the ability to control its rotation through computer programming. Can you identify any interesting characteristics in the servomotor's rotation when programming it for different angles?

Source: Ferreira (2023, p. 30)

When analyzing the responses (Figure 3), it can be seen that the students were able to identify the characteristics of the servomotor and relate them in different ways to the concept of angle.

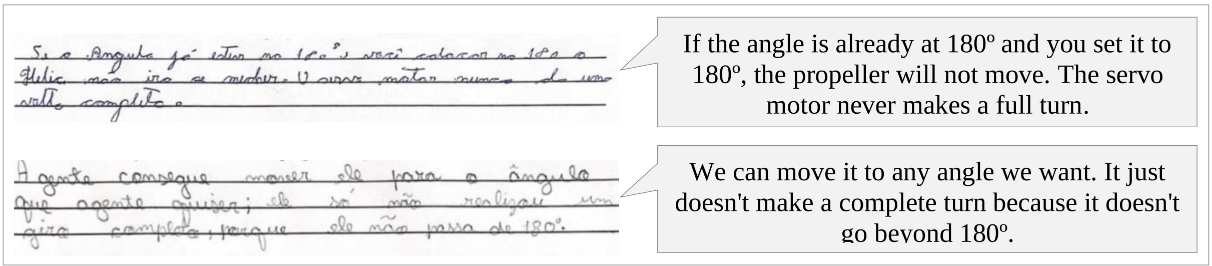

Figure 3: Student responses to question 1 (Ferreira, 2023, p. 31)

The students recognized that nothing happens if the servomotor is programmed to move 180º, after all, its position is already 180º and, furthermore, it does not complete a complete turn because the model used does not go beyond 180º. This demonstrates an understanding of the importance of Robotics for the practical application of geometric knowledge, "because technology motivates learning, encouraging the student to apply and practice what they have learned, investigate and make discoveries" (Perius, 2012, p. 12).

In the second simulation, the goal was to understand how the potentiometer works. Similarly, the potentiometer has three connections: terminal 1 (black wire), cleaner (green wire) and terminal 2 (red wire). The black wire can be connected to any GND port; the green wire to any analog port (the ports labeled AN, with N ranging from 0 to 5); and the red wire can be connected to the 3.3V or 5V ports (according to the datasheet).

To connect the potentiometer to the Arduino board, it must be connected to a breadboard. One student chose the analog port A2 for the green wire and the 5V port for the red wire (Figure 4). Since the red wire can be connected to two different ports, during the practical part, the students were instructed to compare the values obtained in each of these ports. The programming was designed so that, when turning the potentiometer, values were determined until reaching the maximum value.

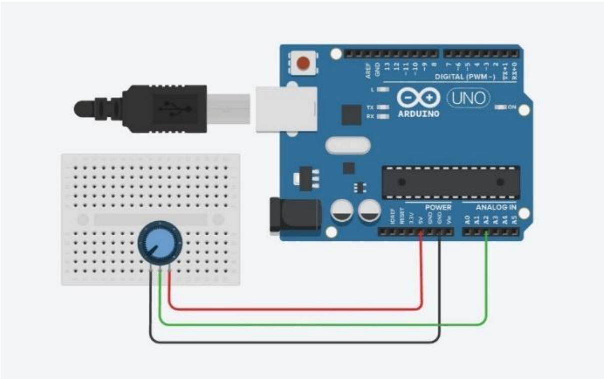

Figure 4: Simulation 2 in TinkerCad (Ferreira, 2023, p. 32)

After making these observations, the students answered the question presented in Table 2.

Table 2: Getting to Know the Potentiometer

2) After completing the second practice of measuring the potentiometer value, record and compare the results with those obtained by your classmates. Based on this comparison, what observations or conclusions can you make?

Source: Ferreira (2023, p. 32)

In this question, students should note that, when selecting a voltage of 3.3V, the values displayed on the serial monitor could vary between different students, while at a voltage of 5V, the maximum value remained constant. This objective was achieved, since most of the answers obtained presented analogies with these characteristics (Figure 5).

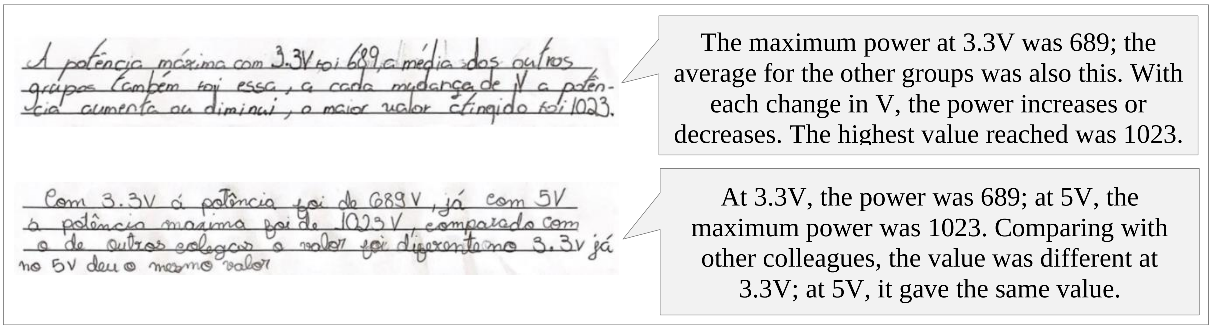

Figure 5: Student responses to question 2 (Ferreira, 2023, p.33)

Figure 5 also shows that the students recognized that, for the 3.3V power, the values measured by the potentiometer varied when compared to those of their peers, but remained close to 689. In addition, they noticed that, for the 5V power, the maximum value increased to 1023, a value that was constant for all. When comparing their answers with those of the others, the students' first reaction was to consider that there could be an error in the connections or in the modifications they made to the program. This attitude reflects the experiences obtained in the context of traditional school mathematics, where the exercises admit exact results, obtained from previously provided data, necessary and sufficient to generate a single and absolute correct answer (Skovsmose, 2000).

This scenario suggests that this activity provided an environment for communication and exchange among the students, in addition to encouraging critical, curious and creative thinking about reality. It was demonstrated that real problems will not always have a single solution. Students often associate the idea of a single answer with a singular way of solving an activity. However, geometric problems, for example, can be solved in different ways, just as occurs in other areas of knowledge and in everyday problems.

In the third and final simulation of this meeting, the students correlated the two previous simulations, recreating the same connections (Figure 6).

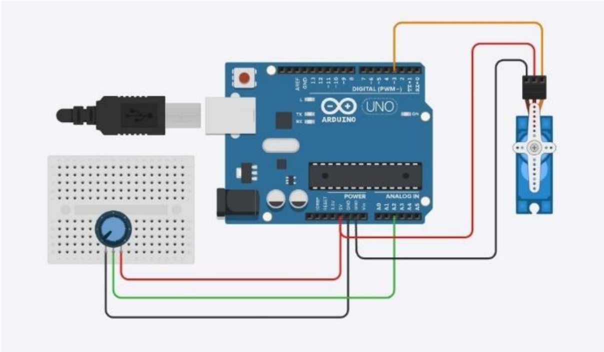

Figure 6: Simulation 3 in TinkerCad (Ferreira, 2023, p. 34)

As a result, when rotating the potentiometer, the servomotor also moved. This occurred because the programming was developed in such a way that, when moving the potentiometer, the servomotor performed the simultaneous rotation, displaying on the serial monitor the rotation angle in relation to the initial angle (0º) (Figure 7).

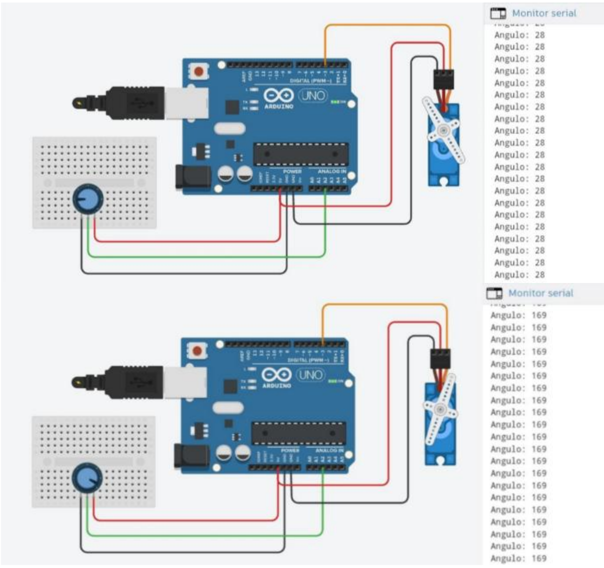

Figure 7: Servomotor movement for angles 28º and 169º in TinkerCad (Ferreira, 2023, p. 34)

Thus, to conclude the first meeting, by drawing any angle, a comparative activity was carried out between the value obtained by the servo's movement and that measured using a protractor (Table 3).

Table 3: Relating the Servomotor and the Potentiometer

3) With the model developed in the third practice, it is possible to obtain approximate values of angles based on the value displayed on the serial monitor. Draw a random angle and compare it with a protractor. What conclusions can you reach by analyzing the differences between the values obtained?

Source: Ferreira (2023, p.35)

Considering that the study of angles is a fundamental topic in the initial stages of Geometry teaching and constitutes the basis for future learning in this area of mathematics, as stipulated by the BNCC (Brazil, 2017), it was expected that students would be able to draw the requested angle. However, when using pencil, paper and protractor, some demonstrated difficulty in completing the task.

Therefore, it is believed that this gap in knowledge can be attributed to the abandonment of Geometry in schools. Since the 1990s, there has been a process of abandonment of Geometry teaching in public schools (Pavanello, 1993). Many mathematics teachers prioritize the study of algebra and arithmetic, as they do not have the geometric knowledge necessary to address this content: “the dilemma is trying to teach Geometry without knowing it or not teaching it at all” (Lorenzato, 1995, p. 2).

Furthermore, due to excessive workloads, many teachers end up using textbooks as the only resource explored in the classroom. Although the documents that guide education in Brazil have made it possible to distribute Geometry teaching throughout the books, this content is still neglected, and is often presented through definitions, properties, and formulas disconnected from logical and everyday relationships (Schmitt, 2017).

By prioritizing the teaching of algebra and exploring Geometry content in a merely expository and decontextualized manner, learning becomes ineffective (Pavanello, 1993). In this context, students tend to memorize the content in a temporary way, with a tendency to forget it after assessments (Faria; Maltempi, 2020). Therefore, according to Andrade (2018), Robotics contributes to the assimilation of content due to its playful nature, thus favoring a more active and meaningful learning environment compared to traditional teaching.

Analyzing the students' responses, it is observed that they associated the differences in values with the concept of precision, indicating which instrument they considered better (Figure 8).

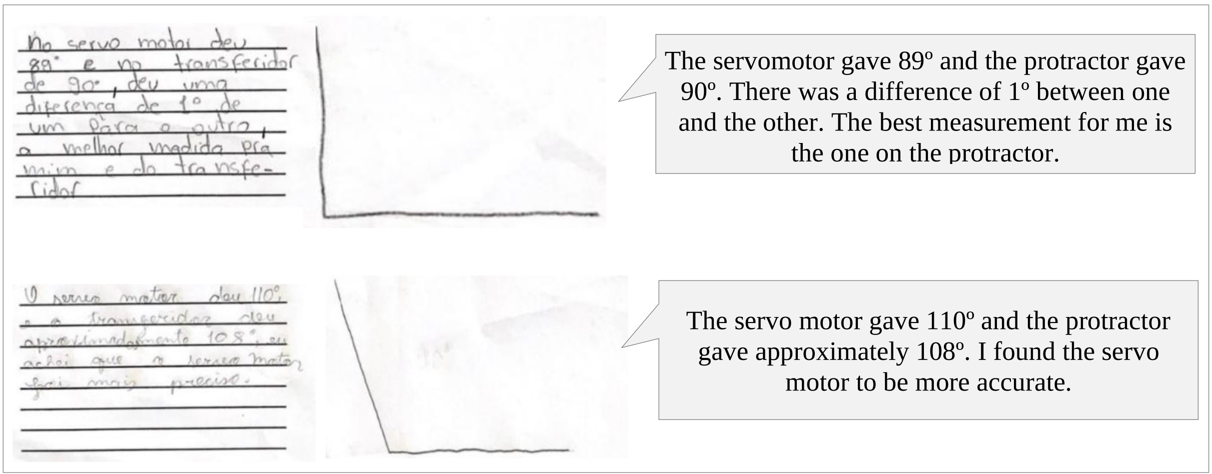

Figure 8: Student responses to question 3 (Ferreira, 2023, p. 36)

As described in Figure 8, while one student pointed out that “The servomotor gave 89º and the protractor gave 90º”, another stated that “the servomotor gave 110º and the protractor gave approximately 108º”. Some of the students considered the value of the angle shown by the servomotor to be more accurate, which may be justified by the innovation and the immediate and digital response that it offers. Others may have chosen the protractor due to their familiarity with the instrument. These differences of opinion promoted, at the end of this meeting, a learning environment that provided the appreciation of different perspectives and instigated curiosity for future activities.

6.2 Finding the value of pi and the length of the circumference

In the second meeting, the process of developing the activities was structured in a way that allowed the students to make the connections more autonomously, based on the instructions contained in the activity sheet, compared to the previous meeting. Thus, the students took on the responsibility of organizing the materials in TinkerCad, choosing the ports, modifying and testing the program, and conducting the process of assembling and physically executing the components. To perform these steps, the students replicated the same connections used in the third simulation. However, the programming of this activity allowed that, by choosing a specific measurement for the radius (in cm) and moving the servomotor using the potentiometer, the calculation of the arc length was displayed on the serial monitor during the movement. After completing half a turn, the measurement of the length of the semicircle was displayed (Figure 9).

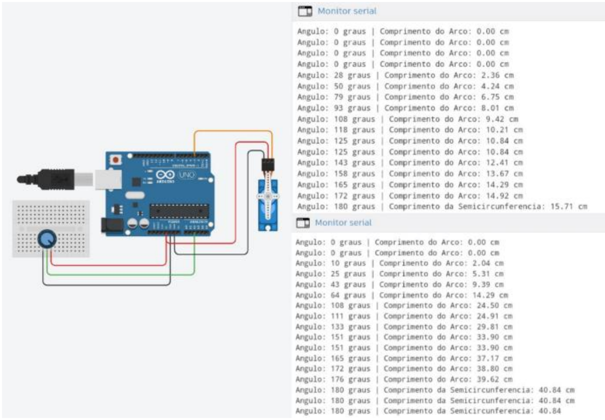

Figure 9: Exploring the length of the semicircle for radius measuring 5 cm and 13 cm (Ferreira, 2023, p. 38)

After completing these steps, students were encouraged to answer some questions on an activity sheet. In the first item, students established different measurements for the radius and wrote down the length of the semicircle (Table 4).

Table 4: Calculating the length of the semicircle for different radius measurements

a) By rotating the potentiometer to an angle of 180º, we were able to calculate the length of half a circle, which we call a semicircle. To explore this, set different values for the radius and write down the results in the table below as they appear on the serial monitor.					
Radius (cm)					
Length of the Semicircle (cm)					

Source: Ferreira (2023, p. 38)

When analyzing the students' responses, it is observed that the majority opted for different measurements for the radius (Figure 10), providing different lengths for the semicircle. It is believed that, as in the school context, it is common to use smaller measurements to simplify calculations, the students adopted a creative and exploratory approach. From this perspective, it is agreed that, in addition to playing an important role in human development, curiosity, creativity and exploration are strongly associated with the development of understanding of geometric concepts (Lorenzato, 1995; Faria, 2016).

Raio (cm)	2.0	10.0	69.0	101.0	666.0
Comprimento da Semicircunferência (cm)	6,28	31,42 cm	216,77 cm	317,30 cm	2092,30 cm

Raio (cm)	69 cm	74 cm	19 cm	43 cm	87 cm
Comprimento da Semicircunferência (cm)	216,77 cm	232,48 cm	59,69 cm	135,09 cm	273,32 cm

Figure 10: Student responses — Item *a* (Ferreira, 2023, p. 39)

In item b (Table 5), students were asked to determine the length of the circumference from the length of the semicircle.

Table 5: Exploring the concept of semicircle and circumference

b) Now, if we want to find the total length of the entire circumference (not just half), how can we do this using the information that a full angle is 360 degrees?

Source: Ferreira (2023, p.39)

In response, the students argued that, since 180 corresponds to half of 360, then the value of the length of the circumference will be twice the length of the semicircle (Figure 11).

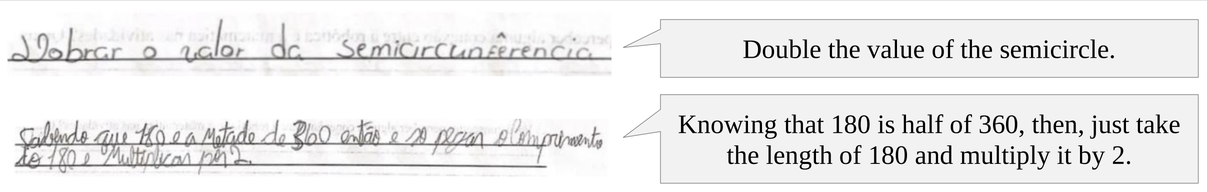

Figure 11: Student Responses — Item *b* (Ferreira, 2023, p.39)

This step allowed students to use their prior knowledge of Geometry to establish proportional connections between these two concepts. According to Faria and Maltempi (2020), stimulating proportional reasoning is essential in Basic Education, as it develops the elaboration of arguments in a comprehensive way. Thus, students who master proportional reasoning tend to perform better in school subjects, as they are able to

> understand the scales of maps in geography, interpret the growth of living beings, which is often proportional to lifespan, in science classes; understand the musical scale and the proportions between the elements in the works of Leonardo da Vinci, studied in art; in addition to many other situations that arise in different school subjects (Faria and Maltempi, 2020, p. 9).

With the data collected in item a), the students calculated the length of the diameter, the circumference and the quotient between the length of the circumference and the diameter, in order to fill in the table available in item c) (Table 6).

Table 6: Table to be filled in by students

c) Using the conclusions obtained in the previous items, complete the table.
Remember: the Diameter is twice as large as the radius.
Circumference Length = C and Diameter = D

Radius (cm)	Diameter (cm)	Semicircle Length (cm)	Circumference Length (cm)	$\frac{C}{D}$

Source: Ferreira (2023, p. 40)

At this point, the students resorted to using a calculator, which, in addition to optimizing calculations, enables, according to Silva (1989), a more reliable and comprehensive path to mathematical formalization.

As they filled out the table (Figure 12), the students began to compare the answers obtained with those of their classmates and gradually recognized a pattern in the results of the calculations. During the process of developing this activity, from choosing the radius measurements to finalizing the table, the students explored their prior knowledge, developed hypotheses, developed reasoning, curiosity and creativity, shared ideas and established connections and relationships. Meanwhile, the researchers played a mediating role, clarifying doubts and providing assistance as needed.

Raio (cm)	Diâmetro (cm)	Comprimento da Semicircunferência (cm)	Comprimento da Circunferência (cm)	$\frac{C}{D}$
2.0	4.0	6,28 cm	12,56	3,14
10	20.0	31,42 cm	62,84	3,142
69	138.0	216,77 cm	433,54	3,141
101	202.0	317,30	634,6	3,1415
666	1332	2092,30	4.184,6	3,14159

Raio (cm)	Diâmetro (cm)	Comprimento da Semicircunferência (cm)	Comprimento da Circunferência (cm)	$\frac{C}{D}$
69	138	216,77	433,54	3,14...
74	148	232,48	464,96	3,14...
19	38	59,69	119,38	3,14...
43	86	135,09	270,18	3,14...
87	174	273,32	546,64	3,14...

Figure 12: Student Responses — Item *c* Ferreira (2023, p. 41)

The search for a pattern is relevant in investigative activities and fosters curiosity. According to Vale and Pimentel (2005), Mathematics is the science of patterns, as it seeks a common structure underlying things that otherwise seem completely different. Even recognizing that there are several meanings for patterns, Vale et al. (2007, p. 15) state that

> in one way or another, the idea remains that patterns, in Mathematics, are associated with discovery, with the search for relationships to explain what we encounter. [...] there is the excitement of discovering something, and a pattern is a discovery. In fact, suddenly, the quantities fit together (there is an order, a regularity, ...) and a relationship is discovered.

At this stage in which they discovered patterns, the students were focusing on tests, explorations and investigations with their groups. As described by Ponte, Brocardo and Oliveira (2003), these actions corresponded to the second stage of Mathematical Investigation. After completing the previous steps, students were asked about the results obtained by dividing the circumference by the diameter. Furthermore, based on this analysis, it was explored whether it would be possible to formulate an equation (Table 7). This phase of discovery, systematization of ideas and reflection therefore determined the third and final stage of Mathematical Investigation (Ponte, Brocardo and Oliveira, 2003).

Table 7: Discussion of the Investigation

d) What did you notice when dividing the Length of the Circumference (C) by the Diameter (D)?
e) Considering the relationship you observed in the previous item, is it possible to create an equation that represents this connection?

Source: Ferreira (2023, p. 42)

When answering item d), the students concluded that, when the length of the circumference is divided by the diameter, the result found is the number π (Figure 13). This conclusion demonstrated that the students understood that, regardless of the radius values chosen, the quotient between the length of the circumference and the diameter is always approximately 3.14. This value, already familiar to the students from previously covered content, facilitated the immediate identification with the number π.

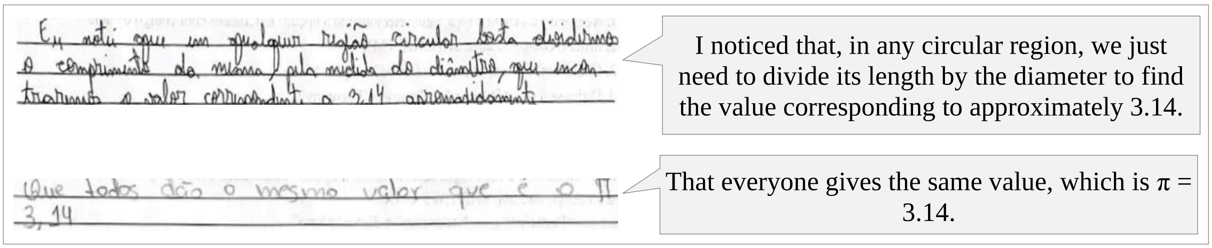

Figure 13: Student Responses — Item *d* (Ferreira, 2023, p. 42)

Understanding the number π through the investigative activities carried out revealed the progression of students' curiosity from naïve to epistemological, the result of the desire to know and understand the object of study in a critical way, going beyond the simple observation or memorization of facts, in an active search for knowledge (Freire, 1996). Thus, the epistemological, complex and conscious curiosity led students to investigate, question and understand what the number π represents.

In addition, the use of Robotics as an innovative and still little explored tool in the classroom encouraged more active and collaborative participation by students. This approach allowed them to develop connections and relationships in an exploratory and engaging way, enabling a broader understanding of the number π, beyond the traditional forms with which they were familiar. In this way, it is believed that we have shared with students that Mathematics, especially Geometry, is not limited to definitions and isolated numbers, but is composed of concepts that emerge from interconnected experiences and studies. In this context, according to Ponte, Brocardo and Oliveira (2003), the students' behavior may resemble the work of a professional mathematician, since they constructed and refined ideas until reaching well-founded conclusions.

As in item d), in which the students observed that the ratio between the length of the circumference (C) and the diameter (D) is equal to π, most of the students formulated the following relationship in item e): $C / D = \pi$ (Figure 14/I). Furthermore, some of them developed this reasoning and concluded that the length of the circumference is equal to twice the radius multiplied by π: $C = 2r\pi$ (Figure 14/II).

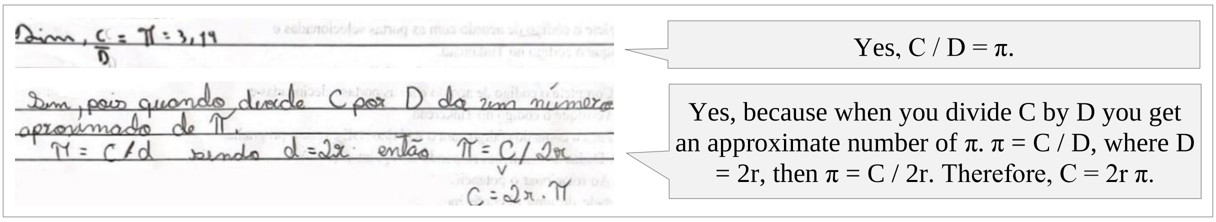

Figure 14: Student Responses — Item *e* (Ferreira, 2023, p. 43)

Thus, even though most students did not fully grasp the formula for the circumference of a circle, the knowledge acquired throughout this process was more significant than would have been the case if they had simply memorized the formula. Thus, it is believed that when students truly understand the content covered and reach conclusions similar to those expected, the connections they establish and assimilate become significant. In other words, meaningful learning not only promotes momentary understanding, but also allows knowledge to be memorized over a long period of time.

7 Final considerations

The data presented in this article allowed us to discuss the stimulation of curiosity through Investigative Activities in Geometry with Educational Robotics in Middle School. The results indicated that Educational Robotics, when incorporated as a pedagogical tool, provided students with a rich and innovative experience, distinct from traditional approaches, favoring a participatory and collaborative investigation environment (Souza, 2023).

In this context, the use of Arduino kit components in the construction of prototypes allowed students to have a deeper contact with the internal functioning of Digital Technologies. As Silva and Blikstein (2020) point out, this experience made it possible to open the black boxes, which aroused students' curiosity and interest as they understood how the devices worked. This involvement not only stimulated curiosity, but also positively influenced the understanding of the geometric concepts involved in the activities.

The development of epistemological curiosity, characterized in the research conducted by understanding the number π through investigative activities, directly dialogues with Freire's ideas (1996). This approach is part of the perspective of a liberating education, which aims not only at transmitting information, but also at forming critical subjects capable of transforming reality. By creating conditions for students to develop epistemological curiosity, the research promoted their emancipation, making them protagonists in the process of knowledge, learning, discovery and critical reflection, in addition to fostering engagement with the world.

The practical application of this knowledge, privileged by the use of robotics during the meetings, provided students with a more effective assimilation of the content. By connecting learning to the students' reality, where technology is increasingly present, this approach strengthened the link between theory and practice, promoting the development of geometric knowledge in a more comprehensive way.

Furthermore, robotics not only offered a new perspective on the application of Geometry to real-world issues, differentiating itself from traditional classroom approaches, but also fostered an environment of communication and exchange among students. This collaborative interaction encouraged critical thinking and the perception that real-world problems, including geometric ones, can present challenges and different ways of being solved. As highlighted by Kenski (2003), the collaborative work provided by robotics enriched the learning process, allowing knowledge to be constructed both individually and collectively.

During the development of the activities, it was possible to observe robotics as a tool that provided creativity, investigation and the development of proportional reasoning in students. This integration with technology significantly enriched geometric learning, making the educational process more engaging and stimulating.

Although these conclusions do not coincide with conventional formulas, such as the circumference, students were able to understand the concept underlying these equations. This understanding may facilitate, in future applications, the recall and effective application of this knowledge.

Therefore, Digital Technologies, especially Educational Robotics, have played a fundamental and transformative role in the development of geometric knowledge, making the learning process more attractive. The use of these technologies in the study of Geometry has provided significant gains, representing a step towards recognizing the potential of technologies as learning tools. Thus, it contributes to breaking with the post-pandemic comparison between Digital Technologies and the character Geni: after all, neither are saviors, nor cursed (Buarque, 1978).

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