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Use of Drones as Pedagogical Technology in STEM Disciplines

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Abstract. With the growing search for qualified professionals in the exact area, teaching in STEM (Science, Technology, Engineering, and Mathematics) areas is gaining importance. In parallel, it appears that drones are an increasingly present reality in the civil area; however, there are few scientific studies of their application in the pedagogical environment, and their insertion is still practically nil in the school environment. Thus, this work aims to analyze the feasibility of using a set of technologies based on drones, designed based on the theory of significant learning through the use of active methodologies. The study was carried out with 30 high school students and followed a line of quali-quantitative analysis, in which the quantitative data were collected from the results obtained in a pre and post-test and the qualitative ones through recordings during the interventions, observations of the researcher, and a semi-structured press interview. Finally, a triangulation between the methodologies was carried out, looking for congruent aspects between the different techniques used. As a result, it was found that the workshops with the platform based on drones helped in the understanding, construction, and interpretation of the content covered, and it can be concluded that there is a significant relationship between the use of the technological set proposed in the pedagogical process and the possibility of significant learning in the STEM areas by the students.

Keywords: drone, educational robotics, meaningful learning, active methodologies.

1. Introduction

Currently, there is a growing demand for professionals in the scientific, exact, and technological fields, which have not been adequately supplied by educational institutions, which represents a major limitation in terms of global development. Here comes the importance of teaching in STEM areas (acronymous to Science, Technology, Engineering, and Mathematics) to boost the creative process, critical thinking, research, and experimentation through science education.

Even those who choose to pursue a career in other areas, outside the STEM areas, need solid training about these contents, as this will allow them to create opportunities in a competitive job market, in which science and technology permeate each more and more practically all areas of knowledge and, more and more, what someone knows how to do with knowledge is gaining more value than the amount of knowledge that someone has.

In many countries, teaching science and technology is a key element in the school process. However, this teaching has been facing several challenges, with emphasis on the students' lack of interest in this category of subjects and the low interest in pursuing scientific careers, which, according to studies, is directly associated with the way science classes are taught, in general, based on a textbook of the discipline and rote learning (Bernardo *et al.*, 2008; Brok *et al.*, 2006; Gow and Bizzo, 2016).

Working in STEM disciplines with active methodologies, the apprentice has the opportunity to develop skills such as leadership, ability to work as a team, improvement in interpersonal relationships, being an effective agent of his/her learning, as he needs to seek concepts to solve the problems proposed by the teacher, who start to act as a mentor or facilitator of the process (Brighenti *et al.*, 2015).

Following the path already outlined in many studies on the use of educational robotics in the classroom (Costelha and Neves, 2018; Bezerra *et al.*, 2018; Plaza *et al.*, 2018; D'Abreu and Bastos, 2015; Gonzáles and Builes, 2009) it is possible to see the emergence of a technology that, for now, is practically ignored or underused by the teaching area: multirotor drones. These robotic equipment present a series of characteristics that make them of high interest to students and teachers, as they enable the realization of a range of activities that can, if well applied, provide moments of different learning, interaction, and reflection for students, for dealing with equipment that has very peculiar characteristics concerning traditional robots.

With this focus, this work seeks to base itself on the theories of David P. Ausubel, creator of the theoretical model of Meaningful Learning, and on the use of active methodologies to verify the applicability of a set of technologies based on drones such as pedagogical technology, which was tested with high school students from an integrated technical course in Informatics.

2. Background

2.1. *Meaningful Learning*

David Paul Ausubel was an American educational psychologist, born in October 1918, in the Brooklyn neighborhood of New York. In the 1950s Ausubel began his studies to build the Theory of Meaningful Learning, which would later revolutionize the field of education, with contributions to the appreciation of the relationship developed between teacher and student, the child's previous and world knowledge (Soares *et al.*, 2017).

Learning for Ausubel (Ausubel, 2000) consists of expanding the existing cognitive structure through the incorporation of new ideas. In this respect, learning can be categorized as rote or significant. In meaningful learning, new information is related to some relevant aspect of the individual's cognitive structure, a subsumer, which allows this new information to be included in the cognitive structure. Thus, this new information is related in a non-arbitrary and substantive way to pre-existing ideas. In rote learning, new ideas or information are not logically and related to concepts that already exist in the individual's cognitive structure. There is no subsumer in the structure to anchor this new information, thus, this new information can be incorporated into the cognitive structure by rote learning, for example through memorization, being stored arbitrarily, having no guarantee of flexibility in use or longevity within the structure.

Subsumers can originate from rote memorization, if the person does not know anything about a particular subject, he will learn by rote until he generates anchor points on the subject in the cognitive structure. As this learning ceases to be rote, generating subsumers in the cognitive structure, it becomes significant, providing anchor points for new concepts. For Ausubel, both meaningful and rote learning are components of a continuous learning process, because sometimes the individual learns significantly, sometimes learns by rote (Ausubel, 2000).

Ausubel (2000) states that learning can be processed in two different ways: by reception or by discovery. In reception learning, despite its name, is not a passive process, since there will be subsumers that will serve to anchor new knowledge, allowing its internalization. In the process of learning by discovery, the content must be discovered by the learner. Unlike Piaget, who emphasizes learning by discovery, Ausubel gives greater relevance to learning by the reception and points out that both can occur by rote memorization.

Ausubel proposes yet another important concept for the origin of the subsumers: the advanced organizers (Ausubel *et al.*, 1980). These are introductory materials, which are presented to the learner before the content itself, to enhance the emergence of non-arbitrary and substantive relationships between new ideas and the individual's pre-existing cognitive structure. They are provisional anchorages for new concepts and can be discarded when significant learning occurs.

The meanings constructed by the students are the result of a complex series of interactions in which there is an action of at least three elements: the student himself, the learning contents, and the teacher, who acts simultaneously as a guide and mediator, leading the process of knowledge construction and motivating the student's participation in tasks and activities that allow him to build meanings that are increasingly closer to those contained in the school curriculum.

Finally, according to Shuell (1990), it is possible to classify the phase of significant learning in which the student is in one of the three described below:

- Initial learning phase: the apprentice finds a large number of facts and pieces of information that, for him, are more or less conceptually isolated; tends to memorize facts and uses pre-existing schemes to interpret isolated data; since it has little domain-specific knowledge, the initial process is global; assimilated information is concrete and not abstract and linked to the specific context in which it occurs; the encounter with a new domain of knowledge involves the rote learning of more or less isolated facts; gradually, the student builds an overview of the new domain, but still struggles to have a clear understanding.

- Intermediate learning phase: new schemes that provide the student with more conceptual power are formed, but still do not allow the learner to behave in a completely autonomous way; more significant forms of propositional and procedural learning predominate and the student must achieve a deeper understanding of the content; knowledge becomes more abstract and less dependent on the specific context in which it was originally acquired; it is possible to use strategies such as concept maps and semantic networks as well as to use information in problem-solving.
- Terminal learning phase: the structures and schemes of knowledge formed during the intermediate phase become more integrated and function with greater autonomy; the learner relies heavily, if not exclusively, on domain-specific strategies to solve problems and answer questions; the greatest emphasis is on performance, not learning; the learning that occurs during this phase probably consists of adding new facts to pre-existing schemes, or increasingly higher levels of interrelationships between the schemes.

In a way, learning should be seen as a continuous process, in which the transition between phases takes place gradually. At certain times during the learning process, there may be overlaps between the different phases. For Shuell (1990) learning in a particular domain never ends, but a point is reached when the learner achieves autonomy (becomes a specialist), giving little attention or exerting little mental effort in the application of assimilated knowledge in different contexts.

2.2. *Educational Robotics*

Second (D'Abreu and Bastos, 2015), educational robotics took its first steps in the USA in the early 1980s, with the development of the Logo language – the result of research by Seymour Papert. One of Papert's criticisms is that, despite the evolution of Information and Communication Technologies with the availability of a range of tools and learning styles, teaching has changed little, maintaining a strong attachment to a curriculum of isolated subjects, with knowledge being transmitted in small doses and verified, in the great majority, through tests in the traditional format.

The learning environment generated by educational robotics promotes meaningful learning, turning classes into experimentation and exploration laboratories. This environment encompasses different areas of knowledge, primarily, disciplines from STEM areas, such as Mathematics, Physics, Electronics, Mechanics, and Informatics, providing an integrating environment for teaching processes (Khine, 2017; Mead *et al.*, 2012; Beniti, 2012).

Educational robotics brings a new look to education where the learner is the agent of the process, being part of the construction of his knowledge, creating and interfering in the environment, not limited to providing rote responses about the environment, but also seeking to give its meaning. By his performance, the apprentice manages to reframe his experience.

2.3. *Active Methodologies*

Formal education in Brazil has faced an existential crisis, not only with regard to teacher training and the teaching methodology used with students but also due to social problems, due to which quality education is slow to arrive with consistency to the poorest (Moran, 2017). To overcome this problem, it is vital to make the educational process relevant and interesting for the target audience, enabling everyone to learn competently to know, build their life projects and live in a society (Seixas *et al.*, 2017; Pontes, 2018).

Moran (2015, p. 19) says: "In active learning methodologies, learning takes place from real problems and situations; the same ones that students will experience later in their professional life, in advance, during the course". In active methodologies the focus is on preparing the apprentice for life and, for this to be possible, the teacher must provide an environment in which the student feels motivated to reflect, to question, and to taste for the knowledge. In this way, the learner plays an active and critical role during the learning process.

For Berbel (2011, p. 28) "active methodologies have the potential to arouse curiosity, as students become involved in theorizing and bring new elements, not yet considered in classes or on the teacher's perspective". The teacher would act as a facilitator or advisor motivating the learner to research, reflect and decide strategies to achieve the established learning objectives, that is, "to develop the learning process, using real or simulated experiences, aiming at the conditions of successfully solving, challenges arising from the essential activities of social practice, in different contexts" (Berbel, 2011, p. 29).

Among the various active methodologies in use in the most diverse contexts, (Suhr, 2016; Valente, 2014; Rocha and Lemos, 2014) this study used Problem-Based Learning (PBL), which differs from the traditional methodology, as it breaks down barriers among the various curricular disciplines, using contributions from different areas of knowledge to propose and solve problems.

In PBL, the learning process is guided by the presentation to students of a problem that is not completely structured to be solved, as would be common outside the classroom. In the problem-solving process, students build knowledge of the content and develop problem-solving skills, as well as self-directed learning skills, promoting an environment favorable to students' metacognitive development.

2.4. *Drones in Education and Related Jobs*

It is already possible to verify the use of drones in the educational area, however, despite the great potential presented by this type of equipment, this use is still quite incipient and limited. Even with the appearance of equipment aimed at the education area, its insertion is still timid in the school environment. In part, due to the costs of this type of equipment, as it is still expensive to set up a laboratory with drones. There are many low-cost drones, however, the vast majority reflects this low cost in the quality of its components and, consequently, in the precision of the equipment (generally difficult to maneuver and low stability).

Equipment with greater stability and precision in the controls tends to be quite expensive. On the other hand, teachers are unprepared to use this technology and there is a lack of landmark studies and methodological proposals that use drones as a teaching tool.

The use of drones in the learning process is still quite incipient, with many studies rambling about and few using drones as teaching technology, in most cases, limiting themselves to the use of this equipment for external use, aiming at capturing aerial images (photo or video) to be used as a subsidy in geography, chemistry, geology or environmental education classes (Fombuena, 2017; Palaigeorgiou *et al.*, 2017; Fung and Watts, 2017) or in more specific robotics and control disciplines, where the drone itself and its programming are the focus of study (Giernacki *et al.*, 2017; Krajník *et al.*, 2011).

According to the study by Sattar *et al.* (2017), the use of drones in education is opening new trends in teaching and learning practices innovatively and engagingly. The study seeks to provide insight to explore different types of drones and their compatibility for use in teaching different disciplines at various levels and suggests that at the primary level of Australia's curriculum, drones can be integrated with the basic content. Basic tasks can be designed, such as a simple flight, route planning, concepts of direction, angle, height, weight, and speed. The key idea is to reinforce the content with the use of drones.

Tezza *et al.* (2020) present a study to encourage the use of drones in the educational sphere and guide teachers in STEM areas on how to integrate drones into their classes. According to the researchers, the main contributions of the study are (1) to generate a discussion about how these systems can be used to teach STEM, (2) to propose a series of guidelines and special considerations necessary when using drones as teaching tools and (3) propose a detailed curriculum for five workshops (distributed in a total of 15 hours) developed to introduce students to drone technologies and increase their interest in STEM subjects.

The study by Joyce *et al.* (2020) aims to develop a proposal to prepare students for future workforce opportunities, where this emerging technology (drones) is being used. The Queensland State Government, Australia, is at the forefront of supporting the emerging drone industry. In 2017, they launched their Drone Strategy, which requires drones to be considered within the school curriculum and included in the Department of Education's science, technology, engineering, and mathematics (STEM) programs. However, introducing drones into educational programs needs to go beyond learning basic flight skills. Thus, the study focused on the use of mini-drones to create a practical, real-world STEM program to teach the fundamentals of geospatial technology with a problem-based learning approach.

The work by Ryu *et al.* (2020) developed an education program with drones, entitled Idaho Drone League (iDrone), aiming to educate and train young people from Idaho (elementary and high school students) to become familiar with drone technologies to broaden and deepen interest students in the STEM fields and create competitiveness for the future workforce. The goal is to continually raise awareness of STEM subjects, attracting highly motivated elementary and high school students.

In two published articles reporting the same experiment, Vostinar and Klimova (2018) and Vostinar *et al.* (2018), an explanation is made about the importance of STEM education through experiences at Matej Bel University and Ján Bakos's elementary school. The STEM focus was Computer Science, and tangible technological devices, such as the Parrot Jumping Sumo drone and the Airblock drone, were used with 8–12-year-old students in two focus groups. Tangible technological devices – drones were used to connect science, technology, engineering, and mathematics. The significant differences between the focus groups were highly motivated students versus "ordinary" students. Reflections on the instruments used for data collection showed that students liked the classes and aroused their interest in STEM areas (Vostinar and Klimova, 2018; Vostinar *et al.*, 2018).

The published study by Bryans-Bongey (2018) reports how the NASA Space Concession Project in Nevada sought to foster a diverse and capable STEM workforce by preparing elementary and high school teachers to plan and teach the STEM curriculum through the use of drones. The project was designed with contributions and specific goals in mind and extended the two-day training experience through the use of an online course and several webinars. According to the study, future projects and research will be needed to expand and assess the effects of using drones in the classroom in terms of learning performance, as well as the impact on career choices and interests.

As it is possible to observe in the reports presented of studies on the use of drones in education, everything is still quite incipient, without effective deepening of the results that are obtainable with the use of this technology in teaching. There are quite bold attempts, as is the case with the curriculum proposal in Australia, however, there is a lack of studies that enable an effective proof of the benefits generated by drone technology. It is clear that researchers are interested in this emerging robotic technology, pointing out possibilities and advantages of its use with students, but it is emphasized that it is still necessary to carry out more specific studies and analyzes its real influence on learning and as a motivator for entry of students in STEM areas.

2.5. *Commercial Initiatives*

There are currently some commercial initiatives that focus on drones for educational purposes. For example, there is the Airblock drone which is an educational robotics kit that emerged as a QuickStarter and is currently being marketed by Makeblock. However, no scientific study was found using specifically the Airblock platform that can effectively validate its use from a pedagogical point of view. Vostinar *et al.* (2018) use this platform as a motivator for teaching computer programming to children from 8 to 12 years of age but need more in-depth studies to verify real effects on the learning process.

According to a report published by Tynker (2017), the Parrot Mambo mini drone is a light, robust, and easy to fly one, even in the case of novice users. The drone has good

Fig. 1. Drone Tello (https://www.ryzerobotics.com).

technology, incorporating high precision sensors, which guarantees excellent stability. In addition to the sensors, there are actuators such as the plastic ball launcher and a claw, which opens up many possibilities for educational robotics projects.

Among the drones analyzed in this study, it was decided to purchase the Tello from Ryze Tech / DJI (Fig. 1). The option was due to safety, flight stability, accuracy, programming options (Scratch, Python, etc.), low cost, and ease of purchase since it is widely sold in department stores in Brazil and easy to get to in internet businesses. Also, the purchase of spare parts such as propellers, engines, and batteries is facilitated and there are several accessories for sale on the market for this small drone.

It was expected that the educational version of this drone would arrive in time to be an option for use in the experiments, but this was only expected, as it was only near the end of the workshops that the Tello EDU was made commercially available in Brazil. However, as it is a novelty, with advanced computer vision resources, its value in Brazil reached approximately five times higher than the version of Tello used in this study.

3. Materials, Environment and Instruments

To make this study feasible, a laboratory was structured to meet the physical requirements necessary to work with drones, as well as a pedagogical and data collection base was built as described below.

3.1. *Physical Structure*

To make the study possible, the environment for the experiments was previously prepared, making it suitable for working with drones in terms of space, equipment, security, and additional necessary resources.

To carry out the study, three Tello Ryze Tech / DJI drones were purchased, each with 4 additional batteries, a set of additional propellers, a charger for three simultaneous batteries, a PGY-Tech protection cage, propeller protectors, and a landing pad drone. The set of batteries allowed more than 40 minutes of autonomy per unit (in no workshop was more than three batteries per drone required).

To carry out the experiments, a computer lab was made available at the Federal Institute of Education, Science and Technology Farroupilha in Frederico Westphalen / RS / Brazil (IFFar-FW), which was adapted in such a way as to provide all the conditions to work with the drones safely and with adequate space for setting up the scenarios in that drones should move. The Laboratory has an area of approximately 70 m2, 13 iMac computers with Intel® Core ™ i5, 8 GB of RAM, 1TB HD, 21.5 "screen and MacOS Sierra OS and 2 Intel® Core™ i3 PCs, 4 GB of RAM, 500 MB HD, 17" screen and Windows 10 OS. It also has an air conditioner, whiteboard, interactive multimedia projector, WiFi open to students, and a security monitoring camera.

It was also necessary to develop or acquire additional objects or materials that would allow the setting up of scenarios with different obstacles that could be deflected or crossed by drones while these traced programmed movements in the air. After evaluation, it was decided to purchase hula hoops (60 cm in diameter) and poufs (35cm high and 30cm on the side). With the hula hoops, it would be easy to assemble and dismantle scenarios with aerial objectives to be crossed, just using strings of different sizes with hooks that would allow their fixation on the structures of the laboratory ceiling. With the ottomans, it would be easy to build terrestrial structures and platforms to be horizontally deflected, transposed, or to serve as a landing point (see Fig. 2).

Fig. 2. Test area for drones with a scenario set up for workshop activity.

Besides, 20 polycarbonate goggles were purchased for use by the students, aiming at safety aspects, 8 measuring tapes for the groups to collect data in the scenarios, and some pen drives for transporting the codes between the computers of the groups' benches and the computers in the area testing of drones.

3.2. *Pre and Post-test*

To have a quantitative view as a complement to the study, a set of questions dealing with the content in focus was selected. With that, it was possible to make comparisons between the performances of the Study Group (SG) and the Control Group (CG), as well as between the participants of the same group before and after the execution of the workshops.

The material was prepared jointly with the professor of the mathematics discipline, aiming to serve as a pre and post-test, including seven exercises contemplating descriptive, objective, and analysis and graphical construction questions. This set of questions is derived from a teacher question bank containing 26 activities of interest to the theme of the workshops. The revised Bloom Taxonomy (Anderson *et al.*, 2001) was used to select the questions, which made it possible to develop an evaluative instrument that would assist in identifying the significant learning stage the student is in after the drone workshops – in Table 1 the classification of the questions used in the test can be observed according to the dimension of knowledge and the dimensions of the cognitive processes (presented with the letter Q followed by a numeral from 1 to 7).

Question 1 (Q1) is linked to the action of remembering specific terminologies and concepts. However, it does not only require factual knowledge for its resolution, it also needs conceptual mastery.

To resolve questions Q2 and Q3, it is necessary to assign some meaning to everyday phenomena or facts inherent to the content of the discipline. The student needs to understand the basic concepts of trigonometry as well as understand the concepts and know-how to associate with the real world.

Q5 was framed in dimension 3 of cognitive processes (apply) and in the dimension of procedural knowledge. Its solution requires the execution of resolution methods. The same occurs for Q4 and Q7, as they are also in the dimension of procedural knowledge.

Table 1
Classification of pre and post-test exercises according to the revised Bloom Taxonomy

Knowledge dimension	Dimensions of cognitive processes					
	Remember	Understand	Apply	Analyze	Evaluate	Create
Factual		Q2				
Conceptual	Q1	Q3		Q6		
Procedural			Q5	Q4, Q7		
Metacognitive						

Finally, questions Q4, Q6, and Q7 are framed in the dimension of cognitive processes to analyze and subcategorized in the conceptual (Q6) and procedural (Q4 and Q7) dimensions of knowledge. To solve them, the student must understand the interrelationship between the parts of the problem, using the appropriate methods and techniques.

In the question bank used, there were no questions that could be classified in the dimensions of the cognitive processes to evaluate and create, nor in the subcategory of metacognitive knowledge.

3.3. *Workshops*

To carry out the experiments, four workshops were designed, each with a set of activities to support learning as described below.

The first workshop sought to introduce students to Scratch and DroneBlocks programming languages and interfaces, presenting their logical structures, potentials, and limitations in program development. In the end, it was expected that the participants would have understood the concepts involved in programming using logic blocks, as well as being able to solve problems using this class of programming language.

The second workshop tried to present the basic concepts about drones, their operation, form of use, and safety aspects. The aim of the workshop, in addition to the introduction to drones, was to learn how to properly configure the programming environment and develop missions for the Tello drone, enabling meaningful learning through the relationship between the fundamental concepts covered in the previous workshop and the new blocks command buttons inserted.

The third workshop aimed at studying the trigonometric function of the sine, presenting its definition and the sine graph. The expected results of the workshop include the understanding of the participants about the concepts involved by the sine function and its application possibilities; structuring of new subsumers to the students' cognitive structure, providing significant learning both in terms of trigonometry and drone programming; and development of a pleasant learning situation, mediated by the interaction between the members of the groups and the use of drones and programming.

Finally, the fourth workshop addressed the study of the cosine function, presenting its definition and the cosine graph. The expected results of the workshop include understanding by the participants of the concepts involved by the cosine function and its application possibilities; structuring of new subsumers to the students' cognitive structure, providing significant learning both in terms of trigonometry and drone programming; and development of a pleasant learning situation, mediated by the interaction between the members of the groups and the use of drones and programming.

The workshops were held in two offers: the first offer with the participation of SG students and the second offer, after the post-test, with CG students. During the last two workshops of the first offer for SG, the CG students had the content of mathematics in the classroom traditionally. These meetings lasted 4 class hours (50 minutes each) and were held for a total of two days in consecutive weeks, slightly more than the duration of the two workshops on the same content with drones (three hours each). Table 2 shows the four workshops in more detail.

Table 2
Description of the workshops.

Workshop	Goals	Necessary subsumers	Activities	Dur.
Workshop 01 Introduction to Scratch	• Introduce students to the Scratch programming language, presenting their logical structures, strengths, and limitations to the development of programs. • Enable meaningful learning through the relationship between preexisting subsumers and the concepts of logic block programming.	• Basic knowledge of building algorithms and programming.	• Work individually in a computer lab (one student per computer) with the interaction between the participants. • Resolution of programming problems with Scratch.	3h
Workshop 02 Programming drones with Scratch	• To present the basic concepts about drones, their operation, form of use, and safety aspects. • Present the specific Scratch logic blocks for programming drones. • Enable meaningful learning through the relationship between programming concepts and drone programming. • Provide a pleasant learning situation, mediated by the interaction between the members of the groups, the use of drones, and programming in a discipline where the use of such resources is not usual.	• Basic knowledge of building algorithms and programming. • Knowledge of Scratch programming. • Knowledge of Cartesian plan.	• Workshop held in the drone laboratory. • Programming of drone missions with Scratch: - space displacement (x, y, z) - variations in acceleration - execution of curves - sensor data control - execution of route and landing on a specific target - diversion of obstacles and achievement of objectives • Group activities featuring three sets of DJI Tello drones. • Activities carried out by the active PBL methodology.	3h
Workshop 03 Drones and trigonometric functions I (Sine)	• Contextualize the trigonometric functions and their practical importance. • Present the constants and variables involved. • Demonstrate how to model real-world phenomena using trigonometric functions. • Enable meaningful learning through the relationship between the concepts of drone programming with practical application of content about sine function. • Provide a pleasant learning situation mediated by interaction, use of drones, and programming in an area where the use of these resources is unusual.	• Basic knowledge of building algorithms and programming. • Knowledge of Scratch programming and drone programming. • Knowledge of Cartesian plan. • Previous knowledge about trigonometry in the circumference and functions. • Knowledge of 3D coordinate system.	• Workshop held in the drone laboratory. • Programming of drone missions with Scratch: - displacement in space (x, y, z) using concepts of trigonometry and knowledge about drone programming; - execution of route and landing on a specific target; - construction of trigonometric formulas to represent the drone's movement in space; - avoiding obstacles and achieving objectives using the sine function. • Group activities featuring three sets of DJI Tello drones. • Activities carried out by the active PBL methodology.	3h

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Table 2 – continued from previous page

Workshop	Goals	Necessary subsumers	Activities	Dur.
Workshop 04 Drones and trigonometric functions II (Sine and Cosine)	• Define the cosine trigonometric function and its form of use. • Present the constants and variables involved. • Demonstrate how to model real-world phenomena using sine and cosine trigonometric functions. • Enable meaningful learning through the relationship between the concepts of drone programming with practical application of the content on the sine and cosine functions. • Provide a pleasant learning situation mediated by interaction, use of drones, and programming in an area where the use of these resources is unusual.	• Basic knowledge of building algorithms and programming. • Knowledge of Scratch programming and drone programming. • Knowledge of Cartesian plan. • Previous knowledge about trigonometry in the circumference and functions, especially the sine function. • Knowledge of 3D coordinate system.	• Workshop held in the drone laboratory. • Programming of drone missions with Scratch: - displacement in space (x, y, z) using concepts of trigonometry and knowledge about drone programming; - execution of route and landing on a specific target; - construction of trigonometric formulas to represent the drone's movement in space; - Avoiding obstacles and achieving objectives using the sine and cosine functions. • Group activities featuring three sets of DJI Tello drones. • Activities carried out by the active PBL methodology.	3h

3.4. *Interview*

At the end of the workshop block, an interview was conducted with SG students. This interview had the main objective to provide subsidy for an analysis of the students' satisfaction regarding the workshops, the use of drone technology for teaching, and the feeling of effectiveness or not of learning.

The researcher's option was for the semi-structured interview to be carried out collectively, aiming at a group interaction in the face of questions, since the response of one of the students can generate responses from others on the topic and foster dialogues that may be of interest to the study. Also, because it is a semi-structured interview, the researcher can conduct the questions in a more flexible way, including new questions if it is interesting for the study or modifying the existing ones, if necessary, for better clarification.

The initial script of the interview was validated by three volunteer teachers, one from the Computing area, one from Mathematics, and one from Methodology, who made comments and suggestions.

3.5. *Sample*

The set of technologies proposed was tested practically with students and teachers of technical education integrated to high school, in the Computer Technician course at the Federal Institute of Education, Science and Technology Farroupilha (IFFar) in Frederico

Westphalen / RS / Brazil. The procedure with the students was carried out only after the approval of the Research Ethics Committees of the institutions involved in the study (UFRGS and IFFar).

The class participating in the study was, at the time of the experiment, attending the second year of high school and the students who wished to participate in the experiment, whose approximate age was 16 years old, were randomly divided into two groups of 15 students each (SG and CG).

During the workshops, the students themselves selected the subgroup of participation by affinity with colleagues (4 subgroups of the SG with 3 or 4 students, defined by affinity). Altogether there were 35 students in the class, of which 30 participated effectively in the study, 3 participated in the workshops without participating in data collection and analysis (they did not deliver the authorizations, but wished to participate in the workshops) and two did not want to participate.

The interventions, in the form of workshops dealing with Scratch Programming and Trigonometric Functions, specific themes of the Mathematics discipline, were given during the regular shift of students so as not to impact the workload of the curriculum structure, with the times and days defined by the management the school in agreement with the teachers involved.

Students who effectively participated in the study, with the respective data collection and participation in the observations, should meet the inclusion criteria listed below. Students who did not meet these criteria could participate in the workshops if they wished, not having their participation, observations, data, and results included in the analysis process.

- **Inclusion Criteria:** The student must be regularly enrolled in the 2nd year of Integrated Technical High School in Informatics at IFFar-FW at the time of the study; the student, if he wishes to participate, agrees to participate in one of the two groups at random, participating in one of the workshops offers; the student must hand the signed consent form to the researcher.
- **Exclusion Criteria:** Students who do not wish to participate or who do not receive authorization from their parents or guardians will be excluded through a consent form to participate in the research.

After prior consultation with students in the class selected for this study, the vast majority showed great interest in participating, so the workshops with the drones were held in two blocks – the first with the SG, while the CG would have the same Mathematics content being passed on in the classroom, in the traditional format; and the second with the CG, addressing the same content and form seen with the EG, aiming to avoid problems of discontent of the participants due to the feeling of exclusion.

3.6. *Data Collection and Analysis Methodology*

This work uses a qualitative approach, which allows analyzing the applicability of the proposed technological set in terms of significant learning but also seeks a quantitative view that supports the analysis and discussion of the results.

As for nature, this work is classified as applied research, as it aims to generate knowledge for practical application in solving specific problems. Its motivation is directed to the resolution of problems that arise at a given moment, focusing on how to put general theories into practice.

Concerning the proposed objectives, the research can be classified as explanatory research, a type of research that is concerned with clarifying which factors are determinant or contribute to the occurrence of a certain phenomenon (Gil, 2012). Explanatory research is the one that seeks to deepen the knowledge of reality, which is why it is strongly anchored in experimental methods.

The data were collected from the results obtained in the pre-test (before the offer of the workshops to the SG) and a post-test (after the end of the offer of the workshops to the SG), recordings of the students during the workshops, notes on the observations carried out by the researcher, final interview with the students, in addition to notes and opinions of the students and teachers involved.

The 30 students participating in the experiment were randomly divided (maintaining the proportions of genders) into two groups with the following structure:

- **Study Group (SG):** 15 participants (08 females and 07 males).
- **Control Group (CG):** 15 participants (07 females and 8 males).

For the treatment of qualitative data, transcriptions of the recordings of the workshops and the interview were made, as well as the notes were organized with the observations collected by the researcher during the conduct of the experiments and the notes left by the students in the lists of activities used in the workshops, the which were analyzed by the researcher from the perspective of the meaningful learning theory.

The data used for the quantitative analysis come from the comparative results of the pre-test with the post-test, on which analyzes were performed with descriptive statistics, including calculation of means, standard deviation, and percentages, followed by analysis with the Student's t-test for independent samples, making it possible to verify the existence of statistically significant differences between the results obtained in the tests (pre and post) with the SG and with the CG.

The combination of the two methodologies (qualitative and quantitative) made it possible to obtain greater knowledge about the focus of the study. In the end, a triangulation was carried out, looking for congruent aspects between the different techniques used that may or may not support the proposal of this study.

4. Pre-test and Post-test Analysis

The moment of applying the pre-test was before the beginning of the workshops, more precisely the day before the first workshop, taking, for its realization, a part of the normal class of the Mathematics discipline. The test duration was limited to two classes (50 minutes class). Table 3 and Table 4 show the test scores (pre and post) performed by the SG and the CG.

Because it is a content that the students had not seen in class, the results obtained in the pre-test were low – with scores varying between 0.4 and 3.7 among SG students and

Table 3
Pre-test and post-test scores of SG students

Study Group (SG)							
		Pre-test			Post-test		
Student	Sex	Score	Deviation	Duad. deviation	Score	Deviation	Duad. deviation
SG01	M	2,00	0,26	0,07	6,10	−0,38	0,14
SG02	M	2,40	0,66	0,44	5,90	−0,58	0,34
SG03	M	2,90	1,16	1,35	9,10	2,62	6,86
SG04	F	1,20	−0,54	0,29	3,50	−2,96	8,88
SG05	M	1,50	−0,24	0,06	6,60	0,12	0,01
SG06	F	3,70	1,96	3,84	8,10	1,62	2,62
SG07	M	2,40	0,66	0,44	4,50	−1,98	3,92
SG08	M	2,50	0,76	0,58	7,20	0,72	0,52
SG09	M	2,20	0,46	0,21	5,00	−1,48	2,19
SG10	F	0,70	−1,04	1,08	7,40	0,92	0,85
SG11	F	0,70	−1,04	1,08	4,30	−2,18	4,75
SG12	F	1,40	−0.34	0,12	8,70	2,22	4,93
SG13	F	0,40	−1,34	1,80	9,00	2,52	6,35
SG14	F	1,40	−0,34	0,12	2,40	−4,08	16,65
SG15	F	0,70	−1,04	1,08	9,40	2,92	8,53
		µ: 1,74		**∑: 12,54**	**µ: 6,48**		**∑: 67,54**

Table 4
Pre-test and post-test scores of CG students

Control Group (SG)							
		Pre-test			Post-test		
Student	Sex	Score	Deviation	Duad. deviation	Score	Deviation	Duad. deviation
CG01	M	1,70	0,35	0,12	3,70	−0,94	0,88
CG02	F	2,40	1,05	1,11	6,40	1,76	3,10
CG03	M	1,70	0,35	0,12	5,70	1,06	1,12
CG04	M	1,20	−0,15	0,02	4,90	0,26	0,07
CG05	F	0,40	−0,95	0,90	5,40	0,76	0,58
CG06	F	0,00	−1,35	1,81	2,00	−2,64	6,97
CG07	M	1,80	0,45	0,21	8,30	3,66	13,40
CG08	F	1,20	−0,15	0,02	8,50	3,86	14,90
CG09	F	2,00	0,65	0,43	2,50	−2,14	4,58
CG10	M	0,80	−0,55	0,30	3,70	−0,94	0,88
CG11	F	2,40	1,05	1,11	3,70	−0,94	0,88
CG12	M	0,20	−1,15	1,31	5,30	0,66	0,44
CG13	M	1,40	0,05	0,00	1,90	−2,74	7,51
CG14	F	0,50	−0,85	0,72	5,30	0,66	0,44
CG15	M	2,50	1,15	1,33	2,30	−2,34	5,48
		µ: 1,35		**∑: 9,52**	**µ: 4,64**		**∑: 61,22**

between 0 and 2.5 among CG students, for a possible total of 10 points – this demonstrated, when analyzing the responses, that for most there were already some subsumers established, but not enough for a complete understanding of the topics covered.

The difference in the pre-test scores between the two groups raised the suspicion of an expressive difference between them, which could influence the result of the experiment. In this way, the Student's t-test was performed to check if there would be significant variation between the mean of the two groups. According to the result obtained in the t-Test, it was possible to observe that the null hypothesis was validated, which confirmed that there was no significant variation between the grades obtained by the students of the SG and the CG.

Regarding the applied post-test, it was nothing more than the same set of questions from the pre-test – it should be noted that the questions from the pre-test had not been commented on, returned to the students, or passed by the correction in class. The post-test was carried out with all participants (SG and CG) after the last workshop by SG. The moment in which the two groups, in different ways, had already covered the test contents – the SG in the workshops and the CG in the traditional class.

As expected, the results were superior to those of the pre-test, as the students had been exposed to the contents covered both in the traditional way (CG) and with the drone workshops (SG). However, visually, a difference in the scores of the two groups was evident, with the scores varying between 2.4 and 9.4 among the SG students and between 1.9 and 8.5 among the CG students, for a possible total of 10 points.

According to the result obtained in t-Test on the scores of the post-test, it was possible to observe that the null hypothesis was refuted, which confirmed the existence of a significant variation, with 95% confidence, between the grades obtained by the students of the SG and CG, with SG students averaging significantly higher than CG.

Performing a general analysis, it is easy to see the concentration of 100% of the pre-test scores in the two initial ranges (from 0 |-- 4) for the two groups (SG and CG), as can be seen in Table 5.

However, it has also more evidence that the SG achieved a better performance than the CG, which is possible to observe more clearly in the accumulated frequencies of

Table 5
General frequency of test scores by range

Range	Study Group				Control Group			
	Pre-test		Post-test		Pre-test		Post-test	
	f_i	f_{ri}	f_i	f_{ri}	f_i	f_{ri}	f_i	f_{ri}
0 |-- 2	8	0,53	0	-	11	0,73	1	0,07
2 |-- 4	7	0,47	2	0,13	4	0,27	6	0,40
4 |-- 6	0	-	4	0,27	0	-	5	0,33
6 |-- 8	0	-	4	0,27	0	-	1	0,07
8 |-- 10	0	-	5	0,33	0	-	2	0,13
	15	**1,00**	**15**	**1,00**	**15**	**1,00**	**15**	**1,00**

Table 6
Accumulated frequency of the SG and CG post-test scores by range

Post-test								
	Study Group				Control Group			
Range	f_i	f_{ri}	F_i	F_{ri}	f_i	f_{ri}	F_i	F_{ri}
0 |-- 2	0	-	-	-	1	0,07	1	0,07
2 |-- 4	2	0,13	2	0,13	6	0,40	7	0,47
4 |-- 6	4	0,27	6	0,40	5	0,33	12	0,80
6 |-- 8	4	0,27	10	0,67	1	0,07	13	0,87
8 |-- 10	5	0,33	15	1,00	2	0,13	15	1,00
	15	**1,00**			**15**	**1,00**		

Table 6, with 80% of the students of the CG with grades below 6, concentrating on the 1 to 3 value ranges (0 |-- 6), while the SG presents only 40% of its grades in these bands, concentrating most (60%) in the highest bands (6 |-- 10), which corroborates with the result from the t-Test to the SG post-test.

For the last analysis on the pre and post-test, the correct answers were compiled per question in each application of the test by group (SG and CG). Based on the cross between the number of correct answers per test question for each group and Table 1 (classification of pre-test and post-test exercises according to the Revised Bloom Taxonomy), a new table was prepared for analysis. For that, open or single answer questions were counted in a unitary way, while questions that contained additional components (additional tasks for the same statement) were computed by the average of correct answers.

The result of this compilation was added to the classification of the question within the two dimensions of the Revised Bloom Taxonomy, encompassing the dimensions of cognitive processes (factual, conceptual, procedural, and metacognitive) and the dimensions of knowledge (remember, understand, apply, analyze, evaluate and create) in which each question was previously classified, resulting in the following table (Table 7).

Analyzing Table 7, there is relative proximity between the pre-test results of the two groups, with a small advantage for the SG in most of the questions, however, according to the Student's t-Test, such difference is not significant, being therefore disregarded. It is also possible to observe that the questions with the greatest number of correct answers are within the dimensions of cognitive processes 1 and 2 (remember and understand) and the dimensions of knowledge 1 and 2 (factual and conceptual knowledge), which would be expected because they have not yet had contact with several concepts covered in the test, having only a few subsumers and advanced organizers who helped answer some of the most basic questions.

Question 6 of the pre-test had a total number of correct answers, but this is probably because it is a multiple-choice question, answered with a high degree of randomness, as was later verified in the researcher's conversations with the students.

Table 7
Total hits per question concerning the revised Bloom Taxonomy

Question	Pre-test		Post-test		Dimensions of the revised Bloom Taxonomy	
	SG	CG	SG	CG	Cognitive Process	Knowledge
1	4,00	2,00	10,00	10,00	1	2
2	11,00	7,00	14,00	13,00	2	1
3	6,00	3,00	6,00	6,00	2	2
4	3,60	3,00	**12,60**	**9,60**	4	3
5	0,00	0,00	**8,50**	**3,00**	3	3
6	6,00	3,00	12,00	13,00	4	2
7	0,13	0,19	**8,50**	**5,25**	4	3

Finally, observing the post-test result in Table 7, there is an equivalence in the number of correct answers for questions 1, 2, and 3, which fall into the dimensions of the most basic cognitive processes 1 and 2 (remember and understand) and in the knowledge dimensions 1 and 2 (factual and conceptual knowledge). However, there is a positive advantage for the EG in questions 4, 5, and 7, which include higher levels in the dimensions, with levels 3 and 4 (applying and analyzing) for the dimensions of cognitive processes, and level 3 (procedural knowledge) of knowledge dimensions – highest knowledge dimension used in the test questions.

Question 6, which requires analytical skills and conceptual knowledge, showed equivalence between the SG and CG tests.

Thus, based on the analysis of the tests used in the experiment, there are strong indications of significant learning on the part of SG students, since they performed better on higher-level questions, despite having similar performance to CG on more basic questions, where rote learning is more detected. There is also the reinforcement given by the Student's t-Test, signaling a significant difference between the means of the post-tests of the SG and the CG.

5. Workshop analysis

Of the four workshops offered, each lasting three hours, the first had an instructional character about programming, and the second presented specifications and fundamentals about drones and served to introduce participants to the three-dimensional coordinate system. The third and fourth workshops already had a more specific focus on the object of study of this work and the time of 3 hours is close to the time of the traditional class for each of the contents. Thus, these last two workshops focused on learning and fixing content on the sine and cosine trigonometric functions, with an emphasis on graph interpretation and mathematical description, using drones as a motivating technology for this purpose.

5.1. *Introduction to* **S***cratch Workshop*

The first workshop took place on the afternoon of November 05, 2019 and aimed to present the two main programming languages based on logic blocks that allow programming missions for drones, in addition to seeking to provide meaningful learning through the relationship between the fundamental concepts of languages with subsumers referring to previous contents of disciplines focused on computer logic and programming.

This first workshop evidenced, according to the researcher's observations, that the vast majority had the necessary subsumers for the acquisition of the proposed new knowledge, however, a small portion (SG04-F, SG11-F, and SG14-F) had quite a difficulty adapting to the tool (Scratch) not understanding its use. These students were more dispersed than the others during the explanations of the concepts and the doubts presented by the colleagues about the statements of the activities. It could be simple disinterest or lack of motivation due to the lack of subsumers necessary for a good understanding.

Reassessing the fulfillment of the requirements of the learning process used (Ausubel *et al.*, 1980), to verify where any obstacle to the due engagement of these students (and others that have not been properly observed) could have occurred, it was found that the fact that the student needs to be motivated to learn may not have been fully achieved, since this includes many variables outside the control of the teacher (family problems of the student, problems with relationships with colleagues, among others).

It was noted that, although the students are at the end of the second year of the course, with programming disciplines since the first year, some still have basic difficulties to structure the logic computationally, preferring, for example, the sequential replication of blocks command instead of using repetition loops.

5.2. *Drone Programming Workshop with Scratch*

The second workshop was held a week later, on the afternoon of November 12, 2019. A brief tutorial on drones was presented, showing their flight characteristics, types of drones, possibilities of use, the characteristics and limitations of the drones that would be used in the workshops, and safety aspects.

Before entering the programming, it had one more important explanation, since it was a mathematical content outside the curriculum of the students that year – the three-dimensional coordinate system. The introduction to the 3D coordinate system was performed using the right-hand rule (Fig. 3), with the direction of the axes used by the Tello drone as a guide. Thus, the mathematics teacher explained the 3D system illustrating with projected images of GeoGebra 3D online (`https://www.geogebra.org/3d?lang=en`) to assist in understanding, and the researcher teacher helped by showing the graphs designed in the form of drone movements within the testing area.

Despite the difficulties in adapting to a new vision of the coordinate system, activities flowed very well in the workshop, with all groups managing to solve the proposed problems.

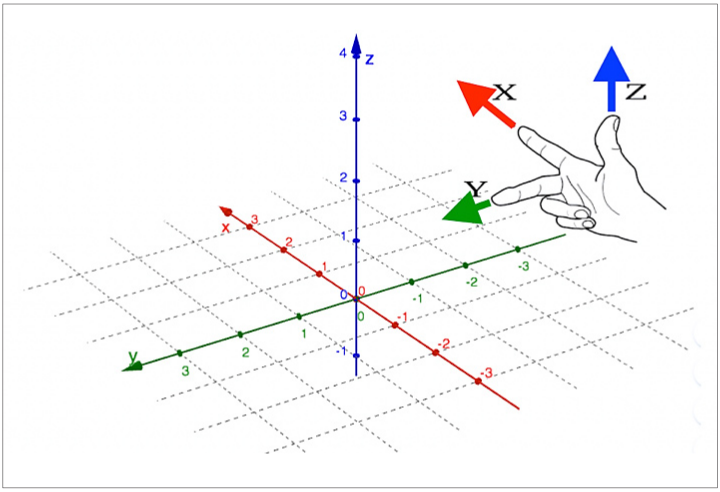


Fig. 3. Right-hand rule for the Tello drone's 3D coordinate system.

It was evident the students' eagerness to load the code on the drones and see if they got it right. Sometimes, when presenting the resulting code (before testing on the drone), the researcher noticed an error and forced a brainstorming between the group to mentally check the movement that would be being performed by the drone.

The researcher acted in this way to prevent students from remaining only in "trial and error", which would overload the use of drones and make it difficult for them to effectively understand the movements within the 3D coordinate system. Thus, the groups would only go to the testing area with the drones if the code was correct (or close to it) or if they needed to understand where they were going wrong. The goal is for them to be able to mentalize the whole problem and its solution before testing, as they were used to doing in the programming disciplines, in which they program and test together until even without being sure why the program works.

One of the activities asked to develop the code necessary for the drone to perform a complete rotation (360 degrees) horizontally, with the front facing the center of the circle. The drone should take off from the center, then it moves the distance of the radius forward and makes a 180-degree turn. In the example image (Fig. 4), the drone is traversing a total of eight positions to complete the circle – this value should be able to be changed by the user, which would change the reference angle for the calculations. Fig. 5 shows an example of Scratch code developed by the students to solve the problem.

It was quite satisfactory, both for the researcher and for the students, since it was clear to both of them the students' understanding of how the drones work, the 3D coordinate system, and the ability to solve more complex problems with little or no help from the researcher professor. This highlighted the possibility of significant learning in the context covered in the workshop, including the fixation of necessary subsumers for the next workshops that would specifically address the sine and cosine trigonometric functions.

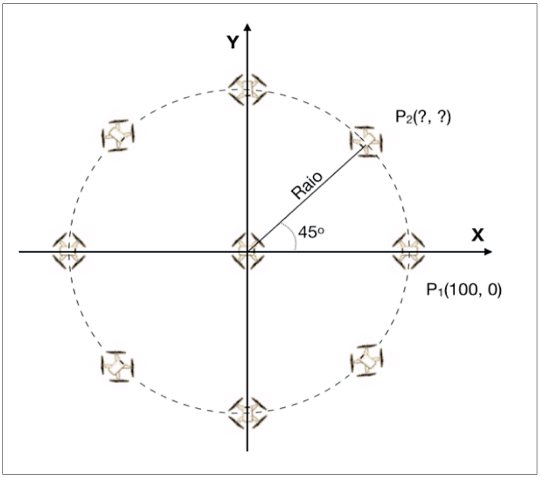


Fig. 4. Image with partial problem data.

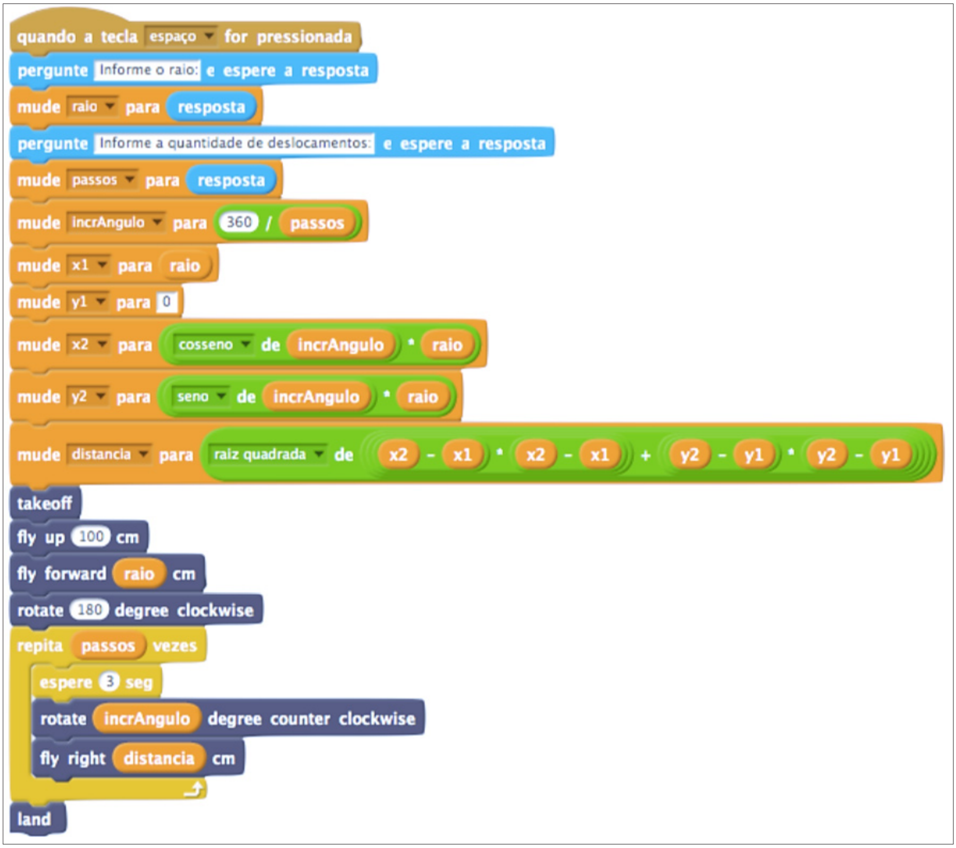


Fig. 5. Example of Scratch code developed by students in the second workshop.

5.3. *Drone Workshop and Trigonometric Functions I*

The third workshop was held a week later, on the afternoon of November 19, 2019. The mathematics teacher started with the transfer of specific content about trigonometric functions (sine function) in the same way that it would be done in a traditional class. It used the same resources that would normally be used with all students, such as the GeoGebra software to facilitate the understanding of the graphics. As in previous workshops, each student received a summary of the content presented by the teacher along with the list of activities for the day.

The students were very attached to the use of GeoGebra, because the software facilitated the understanding of the effects of changes in the variables of the functions on the generated graph and, from what they had observed in the activities with the drones, this would be very useful to be able to properly solve what it was requested. Here the researcher noticed that the drones themselves were already motivating students to understand the content previously, as they wanted to correctly understand what should be done later in the programming and problem-solving.

The first problem was to make the drone execute an XY sine wave at 2m height, with a 4m period and 1m amplitude. The student should consider for the mathematical interpretation the stabilization point of the drone at 2 m high as the origin of XY (0, 0), informing the representative function of the movement, the domain, and the image. The problem served to reinforce the anchoring of subsumers that should already be in the students' cognitive structure. Thus, they should remember and fix the basic concepts of the sine function and the programming of drones with Scratch, especially the construction of curves. Also reinforcing anchor points of proportion, metric system, and 3D spatial vision (being able to visualize the solution of the problem in space).

During the activities, it was possible to perceive how the students were appropriating terms with amplitude, period, domain, and image, incorporating them into their cognitive structure in a natural way, these terms being increasingly used to describe the limits of movements that must be run by drones. The adoption of these terms by the teachers when describing the movements of the drones, helped in the understanding by the students and facilitated the interpretation of the graphs to generate the functions representing the displacements. It is clear here that the teachers used facilitators to acquire the concepts in a significant way by the students (Ausubel *et al.*, 1980), using the advanced organizers such as height, course, distance, already well known and internalized by the students, to assist assimilation of the concepts necessary to the content of trigonometry.

The second activity was developed without major setbacks by the groups, as it was a variation of the first with few addenda. The drone should plot a sinusoid in XY, perform a 180o turn, and return to the starting point by plotting a sinusoid in XZ with a different amplitude. That done, the group should build the functions informing the corresponding domain and image. This activity sought to originate or reinforce, based on the existing organizers, the necessary subsumers for understanding the sine function and its parameters, as well as working the third axis (Z) more effectively, making it part of the problem.

The third problem presented an increase in difficulty when presenting no graphic support for its understanding and adding a displacement on the Y-axis of the initial sinusoid. It took a little while for students to understand these requirements and to be able to solve the problem properly. Initially, most did not understand the displacement of +1 in Y, but as soon as it became clear, they were able to visualize the representation in the sinusoidal function $f(x) = a + b.sin(c.x + d)$.

This problem aimed to reinforce the subsumers on graphs of the sine function, the influence of the function parameters on the displacement of the graph on the axes, changes in the displacement period, and the work with angles. It is worth mentioning that this change of angle, in the case of workshops, has a strong influence on learning about spatial location, since the origin of each new movement of the drone (0, 0, 0) moves to the last position of the previous movement. That is, a 180º turn, for example, means an inversion in the direction of displacement on the X and Y axes.

Problems four and five required students to collect the necessary measures within the scenario, to be able to solve the activity properly. In other words, students should determine the period, amplitude, height, and displacements necessary for the drone to perform sinusoidal movements through the imposed obstacles. In this activity, an unexpected question entered, which was the lack of knowledge by several students of the measurement systems contained in the measuring tapes used. This was detected only when it was noticed that different groups had collected very different values from each other, which should not happen, since it is a set of measures of a fixed scenario in a restricted space. Therefore, the measures should be very close. The students were taking the measurements and, while some were taking the values correctly in centimeters, others were taking the values in inches. The teacher had to give a quick explanation on how to use the measuring tape and the difference between the two measurement systems so that everyone could similarly collect the data in the metric system.

For the fourth problem, students should consider the job description from the drone's takeoff point, having that point as the origin of the system. That is, they should include the vertical displacement on the Z-axis in the function, properly manipulating the function parameters. To do so, they already had the necessary advanced organizers, so it is necessary to fix the concepts previously passed on in the same workshop by the mathematics teacher, dealing with the parameters of the sine function, to create the necessary subsumers for meaningful learning of these concepts.

Once again, the biggest complicator was not the interpretation of the movement to build the function, but the collection of spatial data necessary to solve the problem. All groups were able to solve the problem without major difficulties after having all the necessary data and understanding the entire path that the drone would take in the space defined by the scenario. Thus, in this problem (4), students had to use the measuring tapes made available to collect the necessary data in the test area, knowing only the trajectory of the drone, which should pass through two hoops suspended at different heights, tracing a sinusoid in X and Z, considering a proportionality in which π would be equivalent to 2.2 m.

For the researcher, this initial difficulty is normal, as students are not used to working in this way, having to collect data to solve a problem that is not fully structured.

However, it is an interesting factor to be analyzed, as it represents an innovation in the study that was not foreseen in its entirety. When thinking about working with drones involving the three-dimensional coordinate system, the magnitude of the impact on the students was not visualized. It was possible to observe their evolution in the internalization of this new knowledge in a significant way, in how they wove the relationship with the 2D Cartesian system to which they were accustomed and how strange they found the fact that something so present in their daily life is complicated since they are immersed in a universe that contains, in addition to others, these three dimensions.

The fifth problem, like problems 2 and 3, required an effort by the students in the spatial location concerning the drone's perspective, always thinking about the drone's front position and the right-hand rule. Once again, the problem was provided in a not fully structured manner, with students having to collect spatial data in the scenario and detect changes in the point of origin of each movement.

This problem required a good understanding of the sine function and its parameters, including the displacement on the X-axis, changes in the period and amplitude of the function, and changes in altitude in Z for each new drone path. All of this aiming at anchoring the respective subsumers linked to these concepts and techniques.

5.4. *Drone Workshop and Trigonometric Functions II*

The fourth and last workshop took place on the afternoon of November 26, 2019, along the same lines as the previous workshop. After the explanation of the content by the Mathematics teacher, the resolution of problems with the use of drones began. This time there were only four problems proposed, but of greater complexity than in the previous workshop, covering all the content seen since the third workshop (sine and cosine functions). The Mathematics teacher explained the first problem together with a brief review of the 3D coordinate system and the right-hand rule – erring the hand when checking the right-hand rule was a constant in the workshops, but it was something that the students soon noticed and was not an obstacle to solving problems.

In the first activity, the students should program the drone to perform the path represented by four cosine graphs in movements between points A and B, with a 180-degree turn after each movement (Fig. 6), having to describe later the functions, domain, image, period, amplitude and the proportionality used for π in meters.

The groups worked on coding the problems, collecting scenario data whenever necessary. The students' reaction to seeing the graphical representation of the problems was much milder than in the previous workshop when it seemed something much more complex. It was clear from the observation that they were already able to easily interpret the movements that should be performed by the drone, although they still encountered some obstacles such as the fact that they did not have all the data in the problem statement, having to collect data in the scenario. To make it more difficult, the data that each group collected differed from the data collected by the other groups, which made them unsure as to the fidelity of their collections (Fig. 7). This was also overcome as

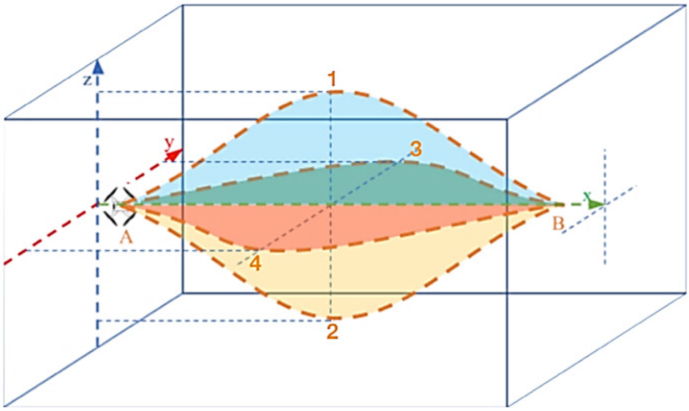
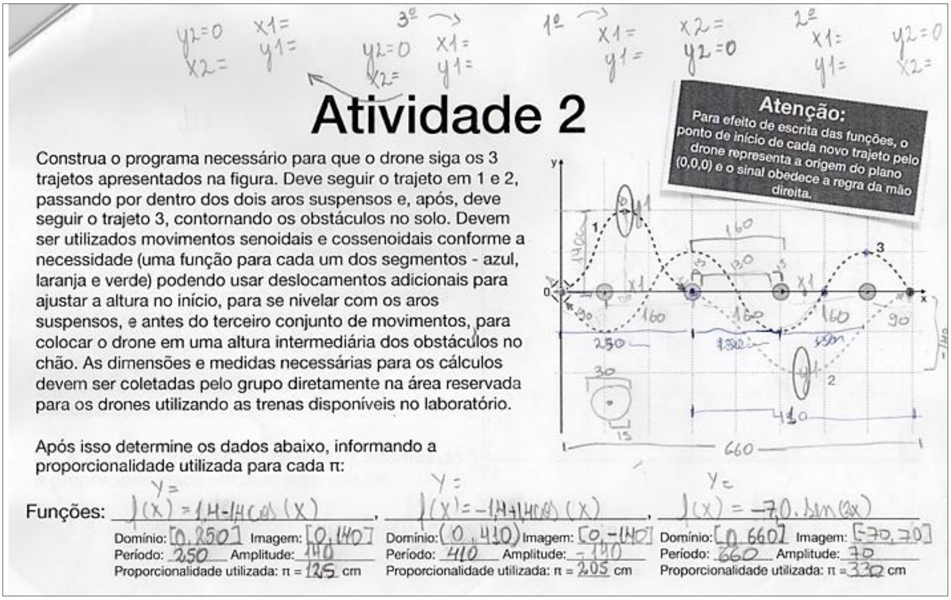


Fig. 6. Illustrative graphic used in activity 1 of workshop 4.

Fig. 7. SG students collecting measurements of the scenario.

they found that, even with different data, they obtained the same results with drones and approximate functions.

After coding, they used the program data and the metrics taken in the scenario to prepare the answers to the trigonometry questions. In Fig. 8, it is possible to see the set of answers and notes made by group 4 on the problem sheet, which helps to understand the line of reasoning followed by the students.



Atividade 2

Construa o programa necessário para que o drone siga os 3 trajetos apresentados na figura. Deve seguir o trajeto em 1 e 2, passando por dentro dos dois aros suspensos e, após, deve seguir o trajeto 3, contornando os obstáculos no solo. Devem ser utilizados movimentos senoidais e cossenoidais conforme a necessidade (uma função para cada um dos segmentos - azul, laranja e verde) podendo usar deslocamentos adicionais para ajustar a altura no início, para se nivelar com os aros suspensos, e antes do terceiro conjunto de movimentos, para colocar o drone em uma altura intermediária dos obstáculos no chão. As dimensões e medidas necessárias para os cálculos devem ser coletadas pelo grupo diretamente na área reservada para os drones utilizando as trenas disponíveis no laboratório.

Atenção: Para efeito de escrita das funções, o ponto de início de cada novo trajeto pelo drone representa a origem do plano (0,0,0) e o sinal obedece a regra da mão direita.

Após isso determine os dados abaixo, informando a proporcionalidade utilizada para cada π:

Funções: y = f(x) = 1,4-1,4cos(x), y = f(x) = -1,4+1,4cos(x), y = f(x) = -70.sin(2x)

Domínio: [0, 250] Imagem: [0, 140] Período: 250 Amplitude: 140 Proporcionalidade utilizada: π = 125 cm

Domínio: (0, 410) Imagem: [0, -140] Período: 410 Amplitude: -140 Proporcionalidade utilizada: π = 205 cm

Domínio: [0, 660] Imagem: [-70, 70] Período: 660 Amplitude: 70 Proporcionalidade utilizada: π = 330 cm

Fig. 8. Sheet with notes and solution to the second problem prepared by group 4.

Problem 3 addressed the displacement of the drone on the X and Z axes, tracing two cosine waves in a row with different amplitudes passing through two suspended rings and, later, returning to the starting point. In general, questions about trigonometric functions were answered quickly and correctly, based on the data used in coding.

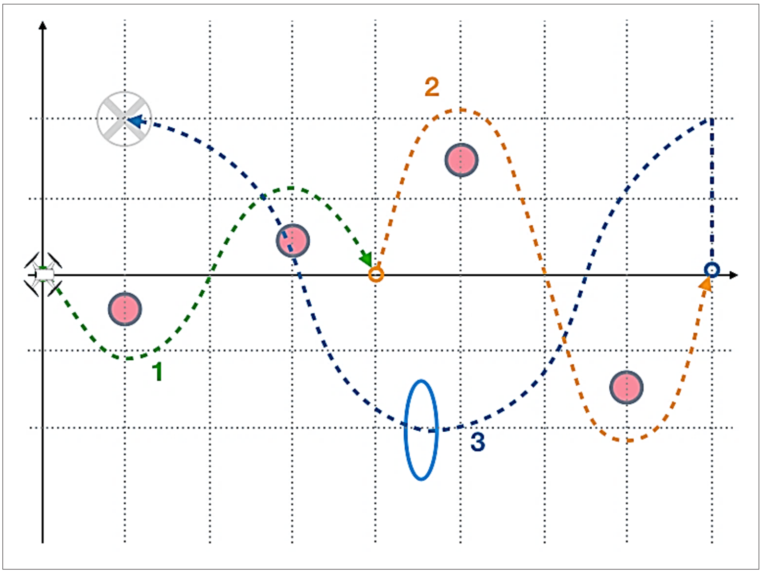


Fig. 9. an illustrative image of problem 4.

The last problem proposed in the workshop, on the other hand, required the construction of two consecutive sine waves with amplitude variation, dodging obstacles on the ground, followed by an inversion of axes (rotation of the drone by 180º) and a cosine motion to return to the landing point, passing through a suspended hula hoop (Fig. 9). All groups were able to solve the proposed problems, some needing additional help from the teacher or colleagues. In both problems, the students had to build the functions that represent the movements, as well as the other data requested by the exercise, based on the data collected in the scenarios and programs developed.

The student SG03-M was one of those who showed greater engagement during the workshops with the drones, both intragroup and intergroup, collaborating whenever required by colleagues and very easy to pass on knowledge. Second (Howland *et al.*, 2012) meaningful learning depends on the students' voluntary engagement around a meaningful activity that involves them in an active, constructive, intentional, authentic, and collaborative way.

6. Interview

The interview sought to follow a script with open questions (semi-structured interview) and was held collectively with SG students in the mini-auditorium of the Informatics building, outside of regular classes. Thus, it occurred on the morning of November 29, 2019, occupying two free classes of students, the day after the completion of the post-test. Of the total of 15 SG students, three did not attend the interview, however, this was not considered a problem, since the representativeness reached 80% of the participants.

As far as the researcher was able to observe, students, in the case of classes in the traditional model, were unable to associate a practical application with the contents. The workshops aimed to reinforce understanding in the construction and interpretation of functions and, it seems, this objective was achieved, with students (or at least most of them) being able to visualize sine and cosine waves more concretely.

Several students, like the SG15-F, agreed that the greatest difficulty was the collection of data in the scenarios. Collecting the measurements correctly to be able to solve the problems was both fun and challenging, with students confusing the units of measurement and the sense of the 3D axes. But everyone agreed that this helped to fix the concepts, not encountering such marked difficulties in the last workshop – some confirm that they would still have problems collecting the measurements, but they would be more logical difficulties in the interpretation of the problem statement, not concerning the measurement system nor the 3D system.

The students stated that they felt easier and more pleased to understand the content and that this type of teaching could be replicated for other content besides Mathematics. It was evident in several comments, the positivity of teaching with active methodologies and educational robotics, as learning ended up impacting even in disciplines that were not imagined, such as Physical Education, where a student reported that, before the workshops, she had difficulty to understand the teacher's commands regarding the spatial location – for example, the order to keep two meters from the colleague was difficult to attend, as she did not have much sense of space. For Shuell (1990), as seen earlier, in the intermediate stage of meaningful learning, the most significant forms of propositional and procedural learning are predominant. The student achieves a greater understanding of the content, being able to reason with it and apply it non-arbitrarily in other contexts.

When asked about their engagement in activities, several nodded positively, signaling commitment, but a good part implied that they did not give their all, with gestures and facial expressions. It was possible to verify that the feeling of engagement, necessary for meaningful learning (Ausubel, 2000), at least in the understanding of the students themselves, was not as it should have been for better use of the workshops. When questioning the students, they did not know how to identify the origin of this feeling, which may be indisposition in certain periods, tiredness, or several other factors.

Finally, after several other questions, students were asked whether the tasks would have been divided according to the preferences of each one – trying to check if there was a division of tasks based on the skills and knowledge of each member, seeking to favor the progress of the work – there was consensus from the majority of the class on this.

7. Results and Discussion

As a final analysis, a triangulation between the qualitative and quantitative methodologies was continued – these methods are complementary, and their combination allows to highlight the strengths and alleviate the limitations of each one, cross data and check if it is possible to reach the same conclusions (Gavira and Osuna, 2015). Here is a summary of that analysis.

Regarding significant learning, when using the Revised Bloom Taxonomy (Anderson *et al.*, 2001) in the classification of the questions used in the tests (pre and post), there is a greater possibility of significant learning in the SG, since they present a greater number of correct answers in questions 4, 5 and 7 (Table 8), which include higher levels in the dimension of cognitive processes and the dimension of knowledge within this taxonomy. This corroborates with the qualitative analyzes carried out on the workshops and the interview, wherein several situations higher cognitive processes of the students were observed that refer to the confirmation of significant learning.

According to Ausubel (2000), effective meaningful learning depends a lot on student engagement, which may explain the not-so-good performance by some of the students in the Post-test. The students SG03-M, SG06-F, SG12-F, SG13-F, and SG15-F, were the ones who had the greatest possibilities of meaningful learning with the anchoring of subsumers and, consequently, higher scores in the post-test. With the ease in explaining how to solve problems to teachers and a high degree of intragroup and intergroup engagement, these five students were the most participative during the workshops, not only helping their colleagues but seeking help whenever necessary with other colleagues and with teachers. It is important to highlight that these 5 students are the ones that stood out the most in the post-test, within the last range (8 |-- 10), as shown in Table 5.

During the interview, it was clear to the researcher that students, in the case of classes in the traditional model, were generally unable to associate a practical application with the contents. Thus, the workshops taught by the ABP methodology in association with the platform based on drones helped in the understanding, construction, and interpretation of functions, reaching the objective of verifying the feasibility of using the platform, with the majority of students being able to visualize a sine and a cosine wave more concretely, in real life and with a more practical application.

The workshops ended up encompassing a series of new knowledge for students or generating subsumers for knowledge obtained by rote memorization so far. This was the case with the 3D Coordinate System and the measurement system, necessary for collecting spatial data from scenarios structured with the platform and a correct understanding of the problems that should be solved by the groups. This new knowledge, as observed in the workshops, showed strong signs of significant learning and promoted the engagement of group participants, since the collection of data from the scenarios stimulated cooperative action.

Evidence of internalization of spatial concepts became clear in situations such as that reported by student SG15-F, for which learning ended up impacting even in disciplines that were not imagined, such as Physical Education, whose activities required to obey commands for which the student needs to have a good sense of spatial location concerning colleagues. Thus, with this example given by the student and other observations cited by the researcher during the study, it is observable that students presented more significant forms of propositional and procedural learning and achieved a greater understanding of the content, managing to reason with it and apply it in diverse contexts, as stated by Shuell (1990).

During the workshops, students' satisfaction with group work and the PBL methodology was clear, as it encouraged them to seek answers and to gather data that were not so evident in describing problems. However, in the interview, they made it clear that the same does not occur in traditional classes, where often the lack of a well-defined methodology ends up making group work a hindrance to the learning process. Most participants think it is important to know how to work together with other people, as it is something that, invariably, will be necessary when they are in the job market.

In the quantitative study, an attempt was made to check if there would be any difference in use between genders, since there seemed to be some female advantage over the male in the acquisition of knowledge, however, according to the Student's t-Test, no change was detected significantly in the final average between sexes that would support this line of thought. Also, in the qualitative part, there was nothing observable that drew attention to follow the study in this comparative aspect. However, analyzing the distribution of grades in the post-test, there is still doubt about the distribution of grades by sex, since, needing further study and analysis, 50% of the members of the female group made better use of drone workshops, with grades greater than 8, while the male group had a more uniform performance, but with only ~14% of students with grades higher than 8.

Finally, it is possible to conclude favorably the central proposition of this work, that there is a significant relationship between the use of the technological set proposed in the pedagogical process and the possibility of significant learning in STEM areas by students.

Therefore, it is confirmed in this research, for the working conditions presented and for the SG and CG used, that the use of an educational robotics platform based on drones as a pedagogical technology, composed of drones, additional components for the construction of scenarios for problem-solving and for a set of STEM activities designed based on significant learning aspects, it promotes the improvement of students' cognitive development by solving problems in the classroom using the ABP methodology. This was observable, both in the quantitative analysis carried out using descriptive statistics and in the qualitative analysis, represented by the workshops and the interview together with the respective triangulation of these analyzes.

No relevant negative points of the drone interventions were detected in the study. In the satisfaction analysis carried out in the interview with the students, it was found that those who showed less engagement in the activities had personal motivations that did not refer to the equipment, but to relationship problems with colleagues and difficulties in working in groups. As negative points of the use of drones in the educational process, it is possible to emphasize the need to train teachers to use this technology. Drones are equipment that, despite being widely available on the market, still have a relatively high cost (in the case of good quality equipment and with good stability in flight). Even so, as a laboratory with some kits can be structured (one drone for every three or four students), it is not a very high investment for an educational institution.

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