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Virtual Experiment on Platonic Solids for Teaching Space-Time Quantization

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Abstract---*The work presents the virtual experiment on Platonic solids in a complementary way, where its importance is crucially used for the treatment of the teaching of the quantization of space-time via loop quantum gravity. The research was part of one of the studies carried out with 23 students in the 3rd year of high school in São Cristóvão, Rio de Janeiro, Brazil. The project is part of several introduced subjects on modern and contemporary physics, as well as frontier research topics. The student starts to have a student-researcher posture and based on Ausubel and Bruner's learning theories, they develop significant learning and receive new information and concepts at the elementary level, conditioning them to a critical and reflective posture. We use the experiment in which students interactively learn three-dimensional shapes, calculate surface area and volume and discover mathematical properties of shapes, necessary knowledge that covers the discussion of the theory. Subsequently, they carried out the skills test and we collected data from the students' operations to present the scenario of innovation and reflection on the possibility of introducing research topics in physics, but with appropriate language for the audience of interest according to Bruner's learning theory.*
Keywords---*platonic solids, quantization, space-time, teaching, virtual experiment.*

Introduction

The research was conducted with 23 students from the 3rd year of high school in São Cristóvão, Rio de Janeiro, Brazil. To use the virtual experiment on Platonic solids to complement the study of the quantization of space-time via loop quantum gravity, obviously at the high school level (Han et al., 2017; Kamarianakis & Prastacos, 2005). We base it on Ausubel's theories of learning, considering learning to be meaningful, Bruner believes that we can teach anything as long as it has the necessary means and languages for the intended audience (Moreira, 1999).

The motivation followed according to the thinking of Moreira (2021), where it sought to develop experimental activities, scientific skills, meaningful learning, dialogic and criticality, with the involvement of research projects in the classroom and the possibility of working with modern physics and frontier research subjects according to the arguments of Stecanela (2015). We increasingly seek to modify the classroom routine as much as possible and bring new elements that will enrich students' knowledge, valuing thinking, and interaction between the student and the teacher, based on reflection and questioning (Nugroho et al., 2021).

We use the virtual experiment in a complementary way because it better concretizes abstract concepts, allowing data collection and hypothesis testing (Sena et al., 2018). The development of the theoretical part of the class held with the students can be found in Silva (2022a). The virtual experiment in the teaching of physics is a non-exclusive, but complementary form, bringing closer to the work of scientists as in theory and practice, taking this analogy in the educational context (Silva, 2022b).

In this article, we will present how we developed in a complementary way with the study of the quantization of space-time through the virtual experiment on Platonic solids and present the results of the activities carried out by the students (Liang et al., 2021; Horng, 2012).

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Materials and Methods

On the first day, we worked with the theoretical part and on the second day, we started to develop the virtual experiment on the Platonic solids to complement the work with the polyhedra and familiarize the students with the concepts of vertex, face, edge, area and volume, as discussed in (Silva, 2022b).

The experiment is on the Geometry 3-D Shapes website, where students interactively learn three-dimensional shapes, calculate surface area and volume, and discover mathematical properties of shapes.

The program aims to analyze the attributes and properties of basic three-dimensional shapes, such as pyramids, prisms, and cylinders, developing mathematical arguments in relationships, such as Euler's theorem. The idea is also to distinguish surface area and volume, calculating both, and exploring in depth the Platonic solids (Vennebush, 2007).

On the third day of the meeting, the students took the skills test, where the students, at the end of the test, generated the pdf test and placed it in a folder on the computer to collect data from the results. The skills test comprises three-dimensional geometry, dealing with surface area and volume, Euler's theorem, and the Platonic solids themselves. The test consists of 39 multiple-choice questions up to option D (Parker & Hess, 2001; Vescio et al., 2008).

Experiments on platonic solids

The experiment on Platonic solids of the interactive site Geometry 3-D Shapes, conditions the student-researcher in the analysis of three-dimensional shapes, such as pyramids, prisms and cylinders, developing mathematical arguments such as Euler's theorem, in contact with the number of faces, vertices and edges of polyhedra. Student-researchers will learn to differentiate surface area and volume, as well as an in-depth exploration of Platonic solids (Zhao et al., 2019; Zhang et al., 2023).

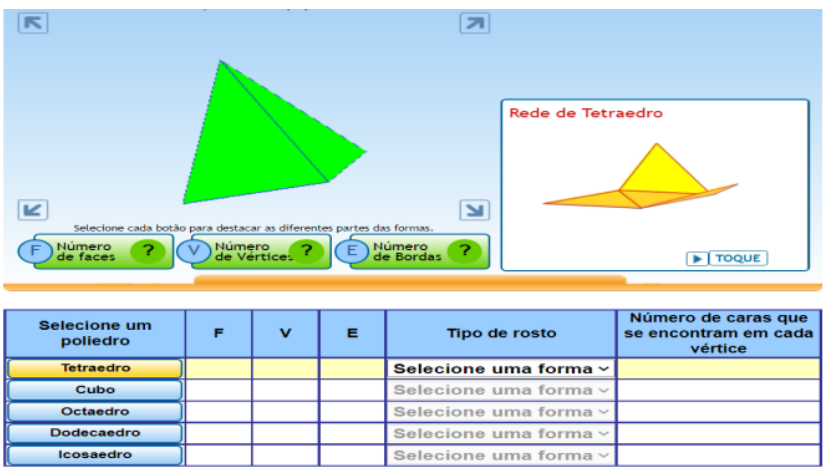


Figure 1. Image of the virtual experiment on Platonic solids (Vennebush, 2007)

Procedure

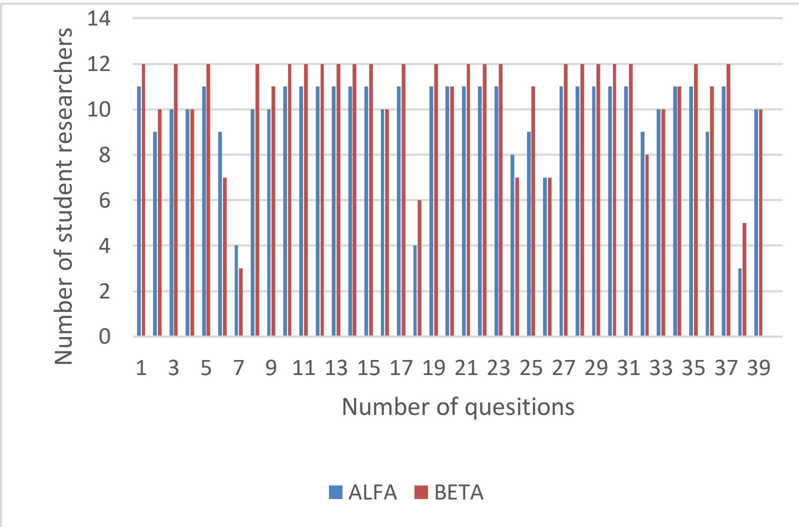
1. The student-researcher will click on the icon of the selected prism, clicking on the number of faces, number of vertices and number of edges. Each item will be shown in green, highlighting the outline of the selected figure. The student-researcher will work only with 5 polyhedra which are Plato's polyhedra.
2. On the right side of the polyhedron, we have the network of the selected polyhedron, by clicking on the "touch" item, see the animation that will start from the projected base to the final predicted figure.
3. Below the figure, we have a table to put the correct amount of the number of faces, vertices and edges of each polyhedron, as well as selecting the type of the face "face" and the number of faces that are in each vertex.

Test your skills

The student-researcher will before testing the skills, click on the intro icons (which is the introduction), 3D shapes, surface area and volume, Euler's theorem and Platonic Solids. These icons will make the student-researcher understand and manipulate geometric figures in 3 dimensions. After all this work of understanding and manipulating the geometric figures, the student-researchers will perform the skill test, generate a PDF, and deliver it to the teacher (Li et al., 2003; Cooper et al., 2015).

Analysis and Discussion of Results

The student researchers performed the skill test on three-dimensional geometry. Data analysis was performed individually. Question 1 presents the image of a tetrahedron and asks what the shape is. Everyone got the question right, given the constant work with the image of the tetrahedron. The geometric figure of the tetrahedron was very marked in the students' memory, given the emphasis on the discussions and the works addressed, so this result was to be expected.



Graphic 1. Skill test on three-dimensional geometry showing the number of correct answers in the alpha and beta groups (Silva, 2022b)

Questions 2, 3, 4, 34 and 36 show open figures. Most of the students answered these questions correctly, given the requirement of constructing the figure.

Questions 5 and 6 ask respectively about Platonic solids and polyhedra, citing some solids for the student to identify. All of them got the fifth question right, given the intense approach to Platonic solids, but in the sixth question there is a confusion of polyhedron and prism.

Question 7 asks which option is true for Platonic solids. It is natural to notice the mistakes in this question because confusion can occur with options C and D, where they say "both are true" and "neither A nor B are true", because the decision is in options A and B. In this question, there was a sharp drop in correct answers, because they associate the faces to the side and to the vertex, which must be careful for geometric perception in this sense.

Questions 8, 9, 16, 25, 26 and 39 deal with the prism and pyramid. The first shows an image of a prism with arrows on two faces on the side, asking for the name of the rectangles that connect the bases of this prism. The second question asks which polyhedron has two congruent bases that are pentagons and five side faces that are rectangles. The third and fourth ask for the number of faces of the pentagonal pyramid and the edge of the pentagonal prism. The fourth asks about the vertex of the octagonal pyramid and the fifth shows what the lateral face of a hexagonal pyramid would be.

Most of them got the questions right and those who got it wrong, put an orthogonal wall on the first one because it appears to be a wall, but this is not the case for the question.

In the second, those who made a mistake considered the pentagonal cube. In the third, those who made a mistake considered 8 or 12 faces. In the fourth, those who made mistakes considered 12 and 14 edges. On Thursday, those who made mistakes considered 8 and 12 vertices. In the sixth, those who erred considered the lateral face of the hexagonal pyramid as a cube, because they made a mistake in reasoning as a base.

Questions 10, 11, 37 are questions that involve dimensionality. The first question is what are the three dimensions of each object, the second is what dimension is missing in the described image, in the case of a computer screen, in the third question what would be the dimension that describes the entire space of a three-dimensional object. Everyone got it right, due to the triviality of the treatment of the space and that was naturally commented on in the classroom.

Questions 12, 13, 27, 28 and 38 involve determining the volume and surface area of the rectangular prism. All of them got the questions right, due to the simple calculation in their application and already discussed in class. On the last question, many got the question wrong, because the question asked to determine the surface area of a prism, it would need to calculate the area of both bases, as well as the area of the side faces, where the students considered the cylinder.

Questions 14, 15, 17, 22, 24 and 30 involve concepts from Euler's theorem to know the number of edges, vertices and faces, being determined in the statement of the question. Everyone got it right due to their knowledge of the theorem and applying it correctly according to the statement.

On the other hand, in question 24, those who made a mistake tried to substitute the figure, because there was creativity on the part of the statement in treating buckyballs, which are chemical configurations discovered by Buckminster Fuller and considered a polyhedron with a certain number of faces and vertices, wanting to know the number of edges.

Questions 18, 19 and 31 involve surface area calculation. In question 18, there was a considerable drop in correct answers on the part of both groups and the alpha group was the one that made the most mistakes in this question because the question shows an open figure of a prism with certain values in its lengths.

Again, it requires students to be accurate in assembling the figure and obtaining the surface area as requested in the statement. Some students answered but discussed that it was different from the values provided for in the options. On the other hand, in questions 19 and 31, all of them were correct, due to the easy applicability requested in the statement.

Questions 20 and 21 deal with cylinder volume. The first with certain values of radius and height, showing the figure, and the second without the figure. Almost all of them were correct in these questions because of the easy applicability requested in the statement.

Question 23 asks how many faces an octahedron has everyone got it right due to previous operations with this geometric figure?

Questions 29 and 35 involve the Platonic solids, with face and edge shapes. In the first question, the shape of the face of the dodecahedron, and in the second, the number of edges of the cube. They all got it right, as they manipulated and discussed the Platonic solids well.

Questions 32 and 33 involve the calculation of the volume and area of the cylinder, with values determined by the statement. Some students made mistakes, as they made a mistake in their calculations, where they considered the exchange of the area for the volume, as well as the height and radius of the cylinder (Silva, 2022b).

Conclusion

The research took place in an exploratory, explanatory and qualitative-quantitative way, with evaluation instruments collected through the virtual experiment. The work in general was designed in such a way as to make the students go through the learning process through the research methodology in the classroom, as well as in the activities that conditioned the interaction with the teacher and classmates, in the search for answers within the expected.

At the beginning of the didactic intervention work, several fears were perceived, mainly due to the different ways of working with the subjects, such as the innovative theme. The insecurity and fear on the part of the students disappeared as the professor-researcher conducted the work, making the students feel like protagonists and part of the research project.

The work, in general, was elaborated aiming to insert a theme of Modern and Contemporary Physics (FMC) and use the learning method with the use of research. These are subjects that are still treated infrequently in the classroom, due to several factors, such as: planning by the school for inclusion in the schedule, equipment for virtual experiments (use of computer or notebook), slide projector for the presentation of images and videos (some schools do not have this type of resource), planning on the part of the teacher, because they must have mastery of the subject to be dealt with by the FMC, planning of the research project, where the teacher must outline the activities considering the period of data search by the students and the time for the execution of the tasks, because there is a natural grid to be followed by the school calendar, which makes this type of activity difficult.

These are some examples that favor the absence of this type of work in the classroom, but if we want students to be protagonists of their education and prepared for social reality, we must train them to make decisions in complex activities, because the world is changing and increasingly needs people with analytical, argumentative, creative, flexible and with an epistemically based structure.

The work does not aim to be an end, but a means, a way to make the student more participative and with a feeling of usefulness, thus increasing the chances of meaningful learning, because the student may in the future even forget about a certain formalism used in this work, but he will never forget that he was part of an activity that became part of a project with the freedom to question and think to solve problems.

We noticed that the manipulation of geometric figures made the students broaden their view of the subject, increasing their motivation for the work, as they started to have a greater perception of the importance of geometric figures for the treatment of the theory. In general, it is hoped that the work can contribute to its application by other teachers and serve as a continuous study for new proposals in various segments of teaching.

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