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Conquering IMO Problems in Brazil by Recognizing the Didactic Situation, Mathematics Teachers Must Know!

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Abstract
Brazilian students, thanks to their expertise in conquering through strategies and techniques in solving problems in problems, have made them famous at the International Mathematical Olympiad (IMO). This resulted in his participation in various competitions with awards such as medals and honorary mentions. This work aims to present mathematics teachers with an international Olympiad Didactic Situation for teaching around any triangle with the support of GeoGebra software. For this, Didactic Engineering is used as a methodological path in four phases (preliminary analysis, a priori design and analysis, experimentation, a posteriori estimation, and formulation) and organized into four stages of Didactic Situation Theory. Finally, one can infer relationships in the epistemic field of mathematics from models built with the GeoGebra tool through knowledge of their geometric representation when considering the insertion of pivotal points of a triangle. In addition, it should be mentioned that Circumcenter Teaching is discussed in didactic experience during the Covid-19 pandemic through propositions about the Olympics. It can be understood that Didactic Engineering based on Didactic Situation Theory allows the didactic transposition of non-trivial mathematical models.

Keywords — Didactic Situation Theory, GeoGebra, IMO, Mathematics Teaching.

Introduction

Brazil has several times participated expressively in the International Olympics. In the International Mathematical Olympiad (IMO), Brazilian students have won numerous gold, silver, bronze, and honorable mention medals. The achievements that have been achieved in IMO are due to the expertise of Brazilian students in choosing strategies and techniques used in solving IMO questions. IMO itself is a mandatory activity held every year since 1959. However, there was an exception in 1980, when, due to financial reasons, no country allowed itself to host international Olympic events (Djukić et al., 2011). In 2019, increasing the record number of participants to 112 countries in remote format in 2020, due to Covid-19 and worldwide social isolation, a series of virtual activities were included for all Olympiad participants through social networks (Impa, 2020).

However, this face-to-face meeting in 2022 will be held in the host country Norway, in the city of Oslo, with all countries participating and other countries interested in this international competition, as Alves (2021, p. 120) points out in "[...] the mobilization of curious people and competitors around the intellectual challenge, the secretive thinking and intelligent showdown, that stem from solving mathematical problems [...]". These participants are selected by each country of origin, sending up to six participants and each competent subject individually, without any interaction or assistance.

Each country sends an Olympic class leader, who participates in the selection of items and is excluded from the rest of the team until the end of the Olympics, and a deputy leader, who guides the participants (Djukić et al., 2011). It is also felt that students with unreliable results being accepted into the discipline have no chance and are far from experiencing the problems discussed in math tournaments.

Given these issues, didactic proposals were presented to teachers working with mathematics olympiads by including Olympic Problems (PO) to incorporate the classroom environment, thus providing students engaged with this Math tournament problem. These situations will be based on the Didactic Engineering (ED) methodology following the perspective of the Theory of Didactic Situations (TSD), which has a primary focus on IMO International Olympic Didactic Situations (SDO), with visualization support in the GeoGebra software, enabling, then, to create an environment teaching that is interactive with OD, which leads to this relationship in student learning.

The work has the following objectives: to present to international DSO teachers for the teaching of any triangular central circle, using GeoGebra as a supporting tool for OP resolution, modeled in the first two phases of DI (introduction to analysis, a priori conception, and accounting) and, organized in the four stages of TSD (action, formulation, validation, and institutionalization).

In the following sections, the theoretical foundations are presented, which relate to Didactic Engineering (DE) and Didactic Situation Theory (TSD), articulated with Olympic Didactic Situations (SDO).

Literature review

This section discusses the theoretical foundation used to support this research. Theoretical foundations within the scope of IMO are also involved at the beginning of the academic study, how the initial activities carried out by DE were followed by TSD, and immediately after that, SDO was included.

Didactic Engineering

DE emerged in discussions outlined at the Institute for Research in Mathematics Teaching (IREM) in France in 1960. In its meetings, IREM developed mathematics teacher training and the elaboration of supporting materials for several classes. The classes in question can be seen in Figure 1.

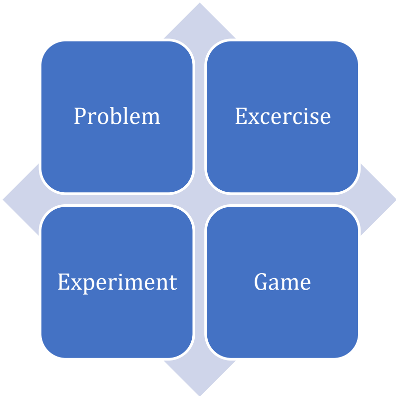


Figure 1. Kelas yang mendukung DE dalam IREM dan elaborasi (Polimer, 2013)

Figure 1 shows that the classes used as an elaboration of material in supporting IREM to develop teacher training categories: problems, games, exercises, and experiments. Thus, DE is characterized by proposing a mode analogous to: "[...] the expertise of the engineer who, to carry out a proper project, relies on the scientific knowledge of his domain [...]", being targeted "[...] to types of scientific control but, at the same time, are forced to work on objects much more complex than those refined in science and, therefore, face [...]" situations "[. ..] that are undesirable or undesirable can be accounted for by science" (Artigue, 1996, p. 193).

DE is defined "[...] by an experimental scheme based on 'didactic realization' in the classroom [...]" (Almouloud & Coutinho, 2008, p. 66). The methodology is organized into four phases: preliminary analysis, a priori design and analysis, experimentation, and a posteriori analysis and validation (Artigue, 1995), including the four phases of the Didactic Technique.

In a preliminary analysis of the center of the circle of any triangle, a study of the content of work in the classroom, its frequent teaching and its reality, the students' conceptions, the problems and obstacles related to its evolution, the interest of the specific objectives of the research and the study of the didactic transposition of knowledge (Almouloud & Coutinho, 2008), which aims to analyze concepts, postulates and ideas that refer to the geometric plane of the circumcenter.

Thus, considering the work's objectives, the following conceptions were conceived: OP visualization to enable problem-solving; GeoGebra software allows learning that involves the critical points of the triangle with the circumcenter subject in dealing with student knowledge.

In the a priori conception and analysis, digital technology is included as a support for mathematics classes. It is a method that differs from the traditional approach that boils down to paper and pencil, which only allows its use for research.

Artigue (1996) reports the teacher's method of action on several didactic variables of an unfixed system, the so-called command variables, which this researcher proposes as variables compatible with the situation studied. The author explains the difference between two types of command variables: macro didactic (global), related to the general structuring of engineering, and micro didactic (local), defined in engineering sessions or stages.

Didactic Situation Theory

TSD begins with the action stage, where students are expected to have a moment to exchange information, considering the problem posed by the teacher. According to Artigue (1984), there are different situations to produce knowledge and information in a secure language, allowing some changes.

In the second stage of formulation, the student justifies his presented description, taking into account previous assumptions, and with the support of GeoGebra software, explores the mathematical properties of the center of the perimeter of any triangle. Santiago & Alves (2021, p. 9), a "[…] way that students begin to use, in solving problem situations, some ideas of a theoretical nature [...]", occurs "[…] more mathematical reasoning dynamic rather than empirical procedures and, with this, it is necessary to apply information to arrive at answers in GeoGebra" (Santiago & Alves, 2021, p. 9).

In the third validation phase, student discourse occurs, analyzing their information with other peers. This phase does not allow teacher interaction with students, allowing them to find the best way to structure the didactic situation of the Olympiad. Students try to use appropriate mathematical language (demonstration) to convince the interlocutor of the truth of the statement; positions of return, action, formulation, and validation characterize (a didactic) teaching situations in which the teacher allows students to follow the path of discovery without showing his teaching intentions and acts only as a facilitator (Brousseau, 1986).

In the final dialectical phase of institutionalization, the teacher has the resolution of the OP exposed so that the student has "[…] a moment of fixation or explicit convention of the cognitive status of a knowledge, or know-how" (Brousseau, 1981, p. 17). In addition, teachers have an essential role in scientific and mathematical knowledge, signifying the problem-solving process of international Olympiads.

Olympic Didactic Situations

The development of SDO is based on TSD, defining that mathematical Olympiad problems are based on dialectics, "a set of relationships established implicitly or explicitly [...]" and occur through the student's interaction with "an environment (I also understand mathematical knowledge approached through competition and Olympic issues) and the education system [...]" (Alves, 2021, p. 125-126).

According to Alves (2020), the definition of teaching with Olympic problems is based on the premise $SDO = PO + TSD$. Thus, it is observed that SDO is equated with PO added to TSD, initiating the teaching intention not by its direct completion but by the way the teacher lays out a path for students to build their mathematical thinking.

Research Methods

The methodological development carried out in this research is based on three emphases in Figure 2.

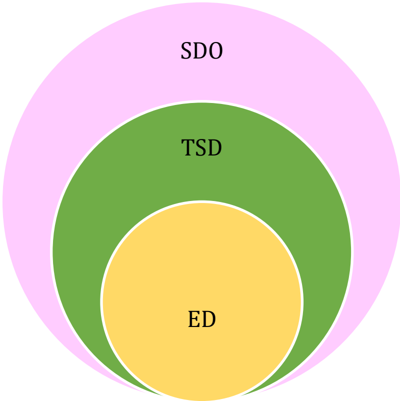


Figure 2. Flow in Conqueing IMO Problem

Figure 1 shows that the method used in this research consists of three stages, namely ED, TSD, and SDO. ED, with an emphasis on the first two dialectics, initial analysis, conception, and a priori analysis, based on TSD, occurs in the implementation of four phases: action, formulation, validation, and institutionalization and based on SDO.

Results and Discussion

Preliminary analysis

In this step, the epistemic-mathematical field will be demonstrated, which addresses selected SDOs from the IMO evaluation held in 2009 in the host country Germany, in the city of Bremen, and the problem put forward by the Russian delegation. In this way, a bibliographic study of subjects related to the context of the mathematics Olympiads was carried out with the books IMO Compendium and Olympiad Training, and both were used for preparation for the mathematics Olympiads (Table 1).

Table 1. Didactic analysis of books for the Olympiad

Publisher/Author	Book	Year
Springer/Dusan Djukic, Vladimir Jankovic, Ivan Matic and Nikola Petrovic	*IMO Compendium*	2011
Sociedade Brasileira de Matemática (SBM)/ Bruno Holanda, Carlos A. Ribeiro, Cícero T. Magalhães, Samuel Barbosa and Yuri Lima	Olympic Training	2020

In this perspective, table 1 above is explained through several books. The textbook chosen for Olympiad training has some mathematical content used to apply problems with the subject of the perimeter of triangles, and it is observed that the authors divide the didactic sequence: theory, proposal of Olympiad questions, and solution methods. In addition, the content explained to students and teachers follows traditional teaching patterns that provide mathematical thinking.

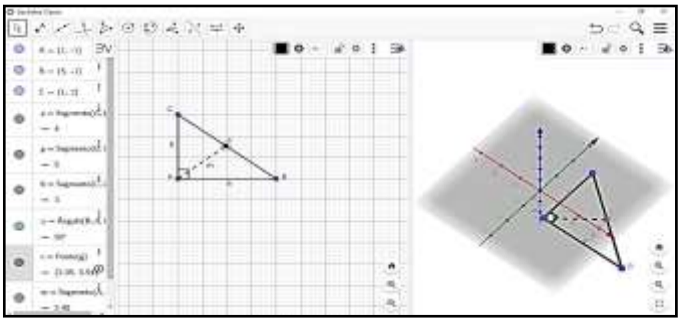
A priori design and analysis

In this phase, the research teacher builds and analyzes the didactic sequence of the international Olympiad to resolve questions and validate the hypotheses represented in the initial analysis. According to Almouloud (2007), its function is to apply new mathematical objects through the interaction of speech and questions that students ask when solving Olympic situations.

IMO 2009 geometry problem, applied on the first day of the competition: Let ABC be a triangle whose center of circumference is O. Let P and Q be the interior points of sides CA and AB, respectively. Let K, L, and M be the midpoints of the segments BP, CQ, and PQ, respectively, and 𝕋 is the circle passing through K, L, and M. Let the line PQ be tangent to the circle 𝕋. Show that OP = OQ.

The first phase of TSD corresponds to a typical action situation: a student discussion and then a problem description. Now, the teacher should encourage students to analyze the data given in the question statement by reading the text of the problem situation.

In the formulation, students must justify their descriptions with previously raised information and, with the help of GeoGebra software, explore the mathematical commands and properties necessary for elaborating SDO.



Figures 3. The SDO setup was developed with GeoGebra software

Similarly, it can be found that the points $AB \,||\, MK$with corners in the segment $\angle PQA = \angle KLM$, are composed of triangles APQ and MKL and prove their equality.

The question is now solved by calculation: $OP/2 - OQ/2 = OB'/2 + B'P/2 - OC'/2 - C'Q/2 = (OA/2 - AB'/2) + B'P/2 - (OA/2 - AC'/2) - C'Q/2 = (AC'/2 - C'Q/2) - (AB'/2 - B'P/2) = (AC' - C'Q)(AC' + C'Q) - (AB' - B'P)(AB' + B'P) = AQ \cdot QB - AP \cdot PC$.

In the debate of problem validation, it is concluded that the points have been constructed by $OP/2 - OQ/2 = 0$. This phase is when students discuss information with other group members.

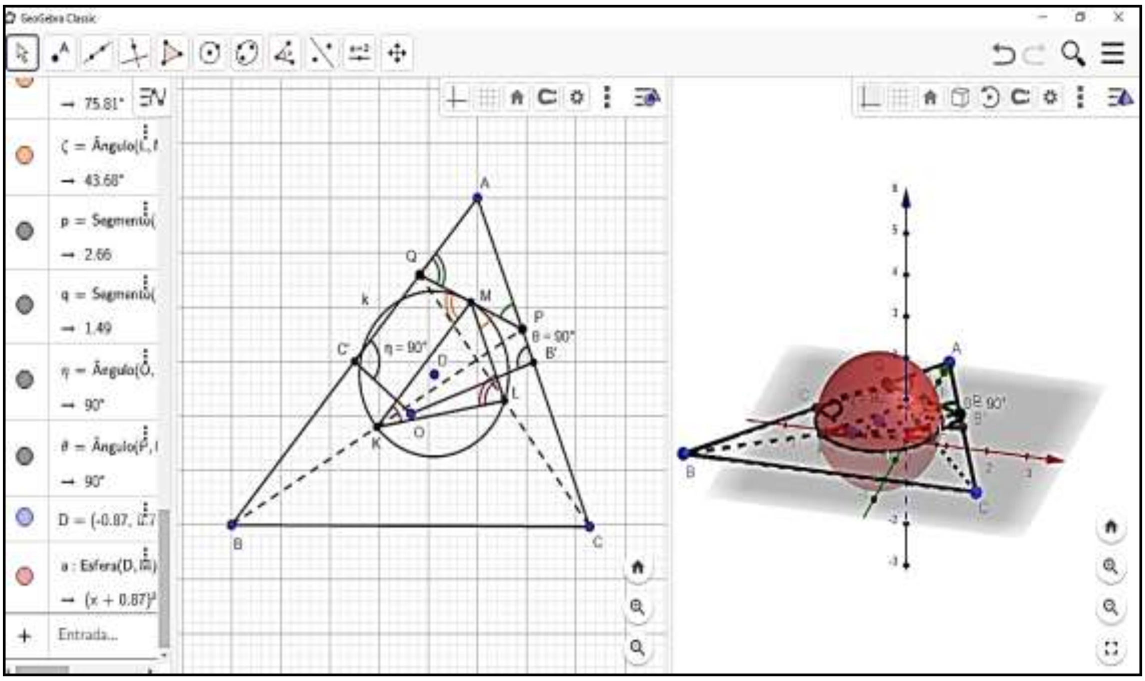


Figure 2. SDO arrangement

In this perspective, there is an institutionalization phase, when the teacher expresses the problem and its solution, characterizes a fixed moment of knowledge, or indicates a state of cognitive learning (Brousseau, 1981), and the teacher takes a leading role in mathematical knowledge.

TEST

The meeting took place via video conference due to the social isolation caused by Covid-19 in all educational institutions worldwide. It was attended by six students from regular schools in the countryside in the municipality of Quixeramobim. Classes take place over four days from 01/25/2021 to 02/26/2021, divided each day into one hour of remote course, plus one and a half hours of monitoring on the instant messaging platform, for ten hours of class.

In this sense, the teacher provides his experience for structuring learning, then instructs the research subject from the didactic contract, then relates to reading problem solving and GeoGebra exploration. At the formulation stage, students exchange the information needed to construct a solution to the problem posed by the mathematics teacher.

Figure 3. A posteriori SDO analysis

From this information, students build mathematical models with the practice obtained at the first meeting and formulate notes on geometric shapes.

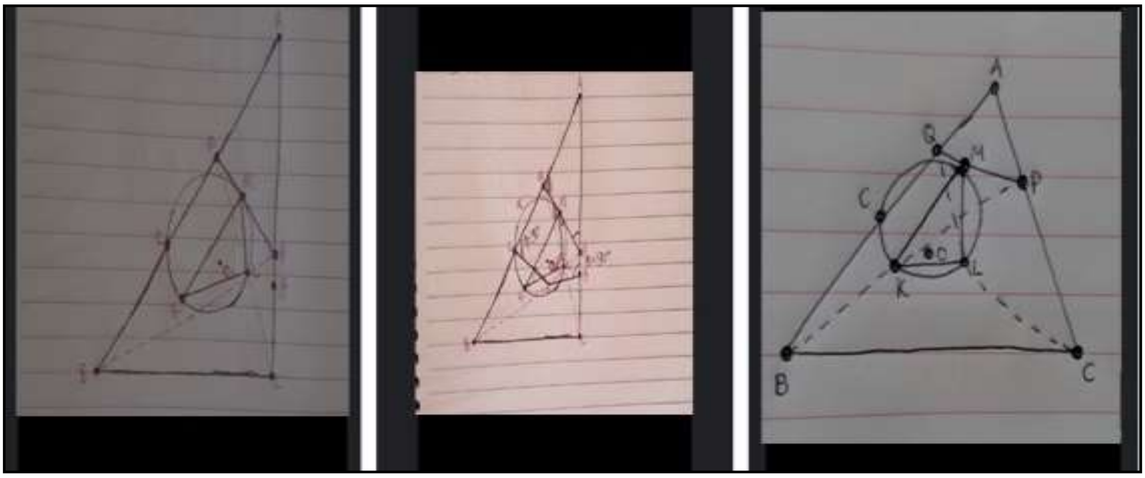


Figure 4. SDO resolution moment

In this section, it is observed that the problem situation described by students using GeoGebra software is available in the instant messaging application with the version explained using paper and pen, and the class is conducted in a distance format due to the pandemic (COVID-19). This means the results are compared with external research, determining external validation.

DATA DESCRIPTION AND ANALYSIS: POSTERIORI ANALYSIS AND VALIDATION

In the final phase of DE, Almouloud, and Coutinho (2008) explain that the learning process through interaction is determined by the properties formed in the representation of mathematical concepts or the geometric definition of the problem.

Thus, the a posteriori analysis depends on situation theory, textbooks, and audio and video recordings, which allows the structuring of the research protocol, which will also be faced with the a priori analysis of the validation of the work objectives through the application of the PO.

FINAL CONSIDERATIONS

The presented work addresses circumcenter teaching and its relationship to plane geometry defined by models built in GeoGebra software. A priori, this content is discussed in the Mathematics Teaching article but adapted for Didactic Mathematics learning.

This didactic transposition is carried out through Didactic Engineering. It is based on structuring the stages of Didactic Situation Theory by considering epistemological assumptions related to mathematics, cognition, and didactics, which are included in the international olympiad questions.

In this sense, one can observe the arrangement presented to the International Olympiad Didactic Situations teacher for the teaching of the circumference of any triangle, followed by the representation created in GeoGebra. In this context, the Olympic problem was discussed by the participating teachers and students in the form of the topic of the essential points of the triangle and its extension to the teaching of the center circumference.

Finally, it is hoped that this research can be included in future classes that attempt to introduce Olympiad mathematics problems to be worked on in the classroom environment. We seek to provide an understanding of DE as a methodological path to transpose didactic content using TSD and SDO, which is intrinsically related to Mathematics Teaching. Therefore, inserting and working on non-trivial math olympiad class questions is extraordinary.

This guarantees the advancement of mathematical thinking and inferential reasoning while solving problems posed by mathematics teachers.

Conclusion

The instructional role of technology is indeed fundamental in the teaching of mathematics. This study shows that technology could catalyze change and methods in teaching mathematics to pupils. Teachers who prioritize their roles as instructional facilitators, mentors, and leaders must likely succeed in fostering mathematical teaching and techniques and helping pupils master mathematics in their schools, as confirmed by the study.

Undoubtedly, the study discovered challenges, as highlighted above, which could affect pupils' quest to learn mathematics through technology. Therefore, it is prudent for policymakers to pay attention to the following recommendations primarily for the attention of the Ministry of Basic and Senior Schools.

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