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# Challenges of abstraction and scientific literacy: an analysis of the video analysis experiment in teaching frame of reference and trajectory in the 1st year of high school[+*]

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**Abstract**

*This work analyzes an experimental video analysis activity on the concepts of Reference Frame and Trajectory, carried out with 1st-year high school students in a state public school in Rio de Janeiro. The methodology was based on the Predict-Observe-Explain (POE) strategy, using the free software Tracker to analyze the movement of a vehicle's wheels filmed on the Presidente Dutra Highway (RJ). The objective was to investigate the transition between visual perception and the physical abstraction necessary for the representation of trajectories in different reference frames. The results revealed a significant gap between digital observation and graphic representation on paper, highlighting difficulties in semiotic transposition. Furthermore, a profound dependence on teacher mediation was observed due to gaps in functional literacy and reading autonomy. In addition, "technological distraction" (use of games and social networks) presented itself as a pedagogical obstacle, requiring restrictive interventions to ensure focus. In conclusion, although video analysis is a powerful tool, its effectiveness in teaching physics is contingent upon*

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*overcoming behavioral and cognitive barriers that transcend the specific content of the discipline.*

**Keywords:** *Physics Teaching; Video Analysis; Software Tracker; POE Methodology; Student Autonomy*.

## I. Introduction

Traditionally, the teaching of kinematics concepts occurs in the first year of high school. In most textbooks from the National Textbook Program (PNLD) (Brasil, 2017, Brasil, 2024), the definitions of reference frame, as the point from which one observes whether a body is at rest or in motion, and trajectory, as the path described by the moving object, are presented in the introductory chapter on kinematics. Both concepts are generally explained using the definition, examples in the form of thought experiments, and/or images.

However, since the concepts of reference frame and trajectory are fundamental to understanding Mechanics and are sometimes not trivial for high school students, an alternative is to seek playful ways to build this knowledge using Digital Information and Communication Technologies (DICT). Thus, *software* such as Desafio Ciência, *Modellus*, *Scratch*, *Física na Escola*, and *Tracker* (Moraes; Maia, 2019; Silva; Veloso, 2020; Oliveira, 2022; Silva Junior *et al*., 2023; Costa; Campomanes; Heidemann, 2024) are used to discuss the concepts of reference frame and trajectory, engaging the digital native student (Prensky, 2001; Kirschner; Bruyckere, 2017) in the medium they enjoy most: technology.

It is important to highlight that in the simulations proposed by Silva Junior *et al* (2023), it is possible to construct the trajectory of a particle on the wheel of a moving bicycle in two reference frames: that of the center of the wheel and that of an observer fixed to the Earth. The importance of this approach lies in the fact that the student, when performing a simulation, perceives the existence of a cycloid when the reference frame is fixed to the Earth. The study by Costa, Campomanes, and Heidemann (2024) presents a methodology analogous to that employed in this research, using video analysis to discuss inertial and non-inertial reference frames.

The cycloidal trajectory, although present in everyday life, is rarely addressed in high school education, leading our students to have the false impression that all trajectories are rectilinear or, at most, sinuous. Among the PNLD textbooks analyzed, only the work of Gualter, Newton and Gualter (2016) discusses the concepts of reference frame and trajectory in more detail, even having a section dedicated to the cycloid with examples and images to facilitate the understanding of high school students.

However, the mere availability of technological resources and illustrative images in textbooks does not guarantee overcoming the epistemological obstacles inherent in physical abstraction (Bachelard, 1996). Although students of this generation are frequently classified as 'digital natives' (Prensky, 2001), a disparity is observed between the ability to use such recreational devices and the technical competence necessary for scientific modeling. In the specific case of the transition between visual perception and the geometric representation of the cycloid, the challenge is twofold: it requires the student to detach their immediate perception of movement and assume the role of an observer in different coordinate systems.

This difficulty in transposition is accentuated when confronted with functional literacy deficiencies and fragmented attention, recurrent in the contemporary school environment. Thus, despite the playful potential of video analysis and the robustness of the free *software Tracker*, the pedagogical intervention reveals that the abstraction process is not automatic. It is necessary to investigate how technological support, while revealing previously invisible characteristics (such as the cycloidal trajectory), can compete with digital distractions that disperse the student's focus (Ramos; Vieira, 2020).

In this sense, the present research proposes to analyze not only the effectiveness of video analysis in demonstrating Kinematics concepts, but also the behavioral and cognitive barriers that prevent students from translating digital observation into structured physical knowledge, especially when challenged to graphically represent what they observe on the screen.

Given this scenario, research was conducted in a state school in Rio de Janeiro. This institution serves a community with a vulnerable socioeconomic profile, but access to ICT (Information and Communication Technologies) is predominantly through *smartphones* and limited data connections, or it refers to a computer lab with fluctuating infrastructure. This scenario is representative of many public schools in Rio de Janeiro, where the pedagogical challenge lies in transforming the available technological resources into an environment for the construction of scientific knowledge, overcoming the view of the computer as a mere entertainment device.

The choice of video analysis as a teaching strategy is justified by its ability to act as a 'bridge' between the concrete and the abstract. By using a video recorded on the Presidente Dutra highway, in a section geographically close to the students' reality, the aim is to reduce the distance between school physics and the lived world. Video analysis allows the student to 'freeze' time and 'track' space, making visible the cycloidal trajectory that is imperceptible to the naked eye. The software in this sense, *a tracker* functions as a mediating instrument that allows the conversion of a vehicle's actual movement into mathematical data and graphical representations in real time.

The central objective of this work is, therefore, to analyze how 1st-year high school students interact with the Predict-Observe-Explain (POE) methodology. In an assistive technology environment, this study aims to investigate whether the confrontation between initial hypotheses (prediction) and evidence generated by the *Tracker* (observation) is sufficient to promote conceptual evolution (explanation), or whether literacy barriers and technological dispersion prevail over the tool's effectiveness. Ultimately, the goal is to understand the limits and possibilities of video analysis as a resource for acquiring data from the observation of characteristics, without the need to reproduce a specific experimental apparatus or situations whose reproduction would often be impossible in a teaching laboratory, as well as to foster autonomy and abstraction skills in teaching contexts marked by profound gaps in basic education.

## II. Theoretical Framework

The concept of video analysis consists of frame-by-frame analysis of videos, enabling the study of different types of movements. These movements are filmed with digital cameras available in *smartphones* or *webcams* and can provide different ways to describe, explain, predict, and understand physical bases (Brown; Cox, 2009; de Jesus, 2014).

For this research, we chose to use the free *software Tracker,* developed by Douglas Brown in partnership with *Open Source Physics* (OSP). It is "a free open-source program that allows for the quantitative analysis of events from videos, providing the generation of graphs and curve fitting to the collected data" (Costa; Campomanes; Heidemann, 2024, p. 3, our translation). Tracker can be downloaded for Windows, MacOS, and Linux operating systems and can also be used in its online version[2].

The POE methodology (White; Gunstone, 1992) is based on the cognitive conflict between what the observer predicts (prior knowledge) will happen in a situation and what they observe to happen, requiring the use of acquired physics knowledge to reconcile prediction and observation. This methodology has constructivist inspiration, since it delegates the responsibility of explaining and debating a given reality, using their own words, to the student, making the teacher a mediator (Santos; Sasaki, 2015). The development of an activity based on this method requires students to perform a task in three stages:

- Creating hypotheses to predict the outcomes of appearances and constructing justifications for that prediction;
- Description of the events;
- Reconciling the conflict between the prediction made and the observation of events as they occur.

Therefore, this methodology allows the student to construct knowledge from the conflict between their prior conceptions and the observation of the event, and may even apply more than one reasoning process to explain what was observed. Santos and Sasaki (2015), in developing a set of external activities for teaching mechanics aimed at the education of young people and adults, highlight that this methodology has constructivist inspiration, delegating to the student the responsibility of explaining and debating a real interest, using their own words. In this context, the teacher plays a fundamental role. According to these authors, "it is up to the teacher to contextualize the theme, present a real interaction related to the form of experiment, video or animation, stimulate the discussion of ideas, organize the interaction of the students

[2] https://opensourcephysics.github.io/tracker-website/

and finally collect and debate the different answers" (Santos; Sasaki, 2015, p. 3506-2, our translation).

*TIC Kids Online Brazil 2024* survey (Comitê Gestor da Internet[3], 2024), 99% of teenagers between 15 and 17 years old have their own profile on the main digital platforms (*Facebook*, *Instagram*, *X*, *TikTok*, *YouTube* and *WhatsApp*), where they spend about 4 hours a day. These teenagers primarily access the internet via mobile phone, which they use to access social networks, send instant messages, play games online, listen to music, and watch videos, programs, movies, or series online (Comitê Gestor da Internet, 2024).

In education, the use of the internet and, more specifically, social media, has resulted in students having difficulty reading and expressing themselves in writing. Social media has fostered the perception that "the vast majority of students master a jumble of information that, however, contains a minimum of learning" (Pertile, Busse, 2014, p. 3).

It is obvious that, in general, internet users find it difficult to concentrate on long texts (more than two pages). It seems that "the more they use the web, the more they have to struggle to stay focused on long stretches of writing" (Carr, 2011, p. 14). In classrooms, this is no different. Teacher narratives have always revolved around the difficulty of concentrating on reading and understanding texts longer than one or two lines, both on the part of the teachers and their students.

Ramos and Vieira (2020) place attention as a fundamental condition for information and experiences to be transformed into knowledge, because, for learning to occur, it is necessary for students to be able to filter stimuli and focus on them, maintain the rules, control their impulses and appropriate the information.

According to the Brazilian National Common Curriculum Base (BNCC) (Brasil, 2018, p.559), one of the skills that high school students need to develop is related to

> *To construct questions, develop hypotheses, plans and estimates, employ measuring instruments, and represent and interpret explanatory models, data, and/or experimental results in order to construct, evaluate, and substantiate conclusions when addressing problem situations from a scientific perspective. (Brasil, 2018, p.559),*

However, the effective development of this skill eliminates literacy gaps that preceded the teaching of Physics. Scientific literacy is not limited to mastering formulas, but also encompasses the ability to interpret technical texts, software manuals, and experimental protocols. In teaching practice, note that a lack of autonomy in functional reading prevents students from using the protocol as a self-instruction guide, generating an excessive dependence on the teacher's oral mediation.

This difficulty in interpretation is consequently reflected in the difficulty of semiotic transposition (Duval, 1993; Duval, 2009). Even though the student can operate the Tracker software intuitively – given their familiarity with digital interfaces (Prensky, 2001) – they

[3] Internet Steering Committee

demonstrate weakness in transferring the trajectory visualized on the screen (a phenomenological datum) to a graphic representation on paper (a scientific datum). As the literature points out (Santos; Curi, 2012; Rabello; Souza; Costa, 2018; Souza; Santo, 2019), the ability to abstract a system of articulations and represent a relative movement requires a level of visual and cognitive literacy that is often not fully developed in basic education.

Therefore, when proposing a video analysis experiment in a public school in a peripheral region, it is imperative to consider that the technological device, by itself, does not fulfill the need for basic interpretation and synthesis skills. The pedagogical challenge then lies in using video analysis not only for teaching kinematics, but also as an exercise in literacy and focus, combating the fragmentation of attention imposed by the recreational use of technologies and stimulating the construction of innovative scientific thinking.

## III. Methodology

This research adopts a qualitative approach, with an exploratory-descriptive character. It is configured as a case study, as it investigates in depth the interaction of a class in the 1st year of high school at a state public school in Pavuna, in the northern zone of Rio de Janeiro. The class has 38 enrolled students, but only 21 participated in this research.

A school serves teenagers aged 14 to 18, residents of a favela complex in Costa Barros, with a low presence of public authorities and dominated by a criminal faction. The region's Social Development Index (IDS) is 0.524, according to the 2010 survey, updated in 2023. [4]It is not possible to obtain the school's Basic Education Development Index (IDEB), as the participation of 3rd-year high school students in the Basic Education Assessment System (SAEB) has fallen below the minimum required for the design in all editions since its creation in 2014.

The students in this research have classes in the afternoon, and the activity was carried out in the school's computer lab, which has 7 computers with internet access [5]. The free *software Tracker* was previously installed on the computers, as was the video used in the activity.

In the classes preceding the activity, the students had an introductory part, in which the basic concepts of kinematics (motion, stability, frame of reference, and trajectory) were introduced in a playful way, with discussion, reinforcement exercises, and examples. The classes were taught in the media room, using slide presentations and videos related to the content.

The students' behavior in the classes preceding the video analysis activity was the same as that observed during and after the experiment: the researcher always drew attention to the topics being discussed; several students were playing games and accessing social media in class; some classmates even showed their scores from virtual games and social media posts to

[4] https://www.data.rio/datasets/5c6396dc70594e4e849c61328c770fde_0/explore

[5] The internet was turned off during the activity to prevent the students from getting distracted.

others; there was a lot of inattention, leaving the room, and absences. Based on their statements, they believe they can answer any question using artificial intelligence (such as ChatGPT or Gemini, for example). In the overall assessment conducted in one of the classes after the experiment, the absent and uninterested students (including some who participated in the experiment) answered less than half of the questions correctly.

Informed Consent Forms (ICF) were also obtained from parents or guardians, and Assent Forms (ACF) were obtained from the students themselves, in accordance with ethical research guidelines, since the participants are adolescents between 14 and 18 years old. The research was submitted to the Ethics and Research Committee of the Federal Institute of Education, Science and Technology of Rio de Janeiro (CEP/IFRJ), under the Certificate of Presentation of Ethical Application (CAEE) number 72936323.9.0000.5268 and approved according to the detailed opinion number 6.420.263.

For data collection, a semi-open experimental design (RES) was used, constructed using the Predict-Observe-Explain (POE) methodology (White; Gunstone, 1992), video analysis data provided by Tracker, and direct observation by the researchers recorded in a logbook.

The RES contains space for students' observations on the specificities of reference and trajectory, a record of observations from the video analysis, and questions that affect the explanation of discrepancies between observations. The semi-open structure encouraged reflection and recording of students' thinking, as can be seen in Table 1.

Table 1 – RES structure related to the POE methodology.

| POE PHASE | SCRIPT FIELD | DESCRIPTION |
|---|---|---|
| Prediction | Introduction | It features video analysis and the open-source Tracker software; It asks the student to watch the video Videoanalysis_1. |
| | Building Hypotheses | The student makes predictions about the car's trajectory for observers in three reference points: on the sidewalk in front of the movement, at the center of the front wheel, and at a point on the edge of the wheel rim. |
| Observation | Preparing the experiment | It guides the student on how to use the video trimming adjustment tools, measuring stick, and coordinate axis insertion. |
| | Taking measurements | Guide students on how to mark the object's position using the track tool in the software. Tracker for data acquisition. |

| | | |
|---|---|---|
| | Analyzing the data | The students record, for each observer, the graphic construction performed by the Tracker. |
| Explanation | Building Conclusions | The students compared their predictions to the information obtained from Tracker, in a guided manner, and justified their answers based on what they learned in the experiment. |

Source: Authors.

The aim of the study was to compare the trajectory observed by the students from three different reference points: an observer positioned on the sidewalk facing the event; an observer in the center of the front wheel; and an observer at a point on the edge of the wheel.

The video used for this video analysis was recorded on the Presidente Dutra Highway, near São João de Meriti, at noon, using an iPhone 12, in slow motion at a rate of 120 frames per second (fps). The device was positioned horizontally, held firmly with both hands, and with the rear camera parallel to the plane of the car's position (Fig. 1).

*Fig. 1* – A frame *from the* video recorded for video analysis.

The video is 1 second long, and the segment used by the students for video analysis is between frames 53 and 100, thus allowing for the scoring of 47 points.

For the reference measurement (measurement for basic accuracy in Tracker) the vehicle's wheelbase (2,469 m) was used, which was obtained with the help of the Google Lens tool[6].

The materials used in this research (semi-open experimental script, video and video analysis tutorial) are available in the Laboratório Virtual de Cinemática (LaViC )[7].

[6] The *software The lens* was developed by *Google* in 2017 and is designed to provide relevant information using visual analysis. Source: https://pt.wikipedia.org/w/index.php?title=Lente_do_Google&oldid=63677769.

[7] The Virtual Kinematics Laboratory (LaViC) is an educational product developed by the authors for research and is available at https://sites.google.com/view/laboratoriovirtualdecinematica

## IV. Results and Discussion

A video analysis activity on frame of reference and trajectory was conducted in the school's computer lab during two 50-minute class periods. Students worked in pairs, in trios, or individually, using the software. Tracker and following the guidelines of the semi-open experimental script.

In the Prediction section of the lesson plan, the students watched the video without any intervention. Then, they moved on to constructing hypotheses, where they had to answer observation questions by drawing the trajectory in the following situations:

- Situation 1 – A point in the center of the front wheel for an observer viewing the movement of the sidewalk;
- Situation 2 - A point at the edge of the front wheel rim for an observer viewing the movement of the sidewalk;
- Situation 3 - A point at the edge of the front wheel rim for an observer viewing the movement of the center of the car wheel;
- Situation 4 - A point in the center of the wheel at the front of the car, as seen by an observer watching this movement from a point at the edge of the wheel rim.

The students' responses were verified, and the standards presented in Table 2 were defined. To ensure the security of the data from the students who participated in the research, each script was identified by a randomly generated code.

Table 2 – Pattern of student responses to situation 1 in the "Building Hypotheses" section.

| **With response** | | **Number of students who chose the response pattern** |
|---|---|---|
| **Format** | **Content** | |
| Design | Only the wheel | 3 |
| Design | A wheel/car on the track | 6 |
| Design | Two wheels/cars with an arrow/line between them. | 6 |
| Design | Two wheels/cars with an inspiration between them. | 2 |
| Writing | The observer on the sidewalk saw the car in motion, and the driver of the car saw the observer in motion. | 2 |
| Drawing/Writing | Others | 2 |

Source: Survey data.

One student drew a circle in each of the four proposed situations. Their answers were as complex as "Other". For situation 1, the other student drew a wheel with several arrows coming out of it in all possible situations and, next to the wheel, an arrow pointing to the right side with the word “rim” written above it (Fig. 2).


*Fig. 2 – Drawing made by student E04 for Situation 1.*

In this situation, students were expected to draw a straight path, establishing that, for an observer in the sidewalk's frame of reference, the center of the wheel rim indicates a straight line of motion. Note that six students drew two wheels with a straight line connecting their centers (Fig. 3).

*Fig. 3 – Drawing made by students E11, E13 and E14 for Situation 1.*

Table 3 presents the response data patterns for situation 2, in which the observer is in the sidewalk frame of reference, but the student is asked to draw the trajectory of a point at the edge of the hoop.

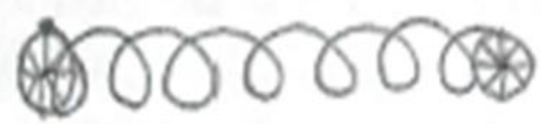

*Fig. 4 – Drawing made by students E05 and E06 for Situation 2 .*

In situation 2, the student is expected to identify, through drawing or words, that the trajectory of a point at the end of the front wheel is a cycloid. The response that most deviated from this expectation was from a student who drew two wheels connected by an inspiration (Fig. 4). As there were no other similar responses, this student appears in the “Other” line of Table 3.

Table 3 – Pattern of student responses to situation 2 in the “Building Hypotheses” section.

| **with response** | | **Number of students who chose the response pattern** |
|---|---|---|
| **Format** | **Content** | |
| Design | Car on the track | 5 |
| Writing | Straight line | 5 |
| Design | A wheel with a straight line next to it. | 3 |
| Writing | Walk forward | 2 |
| Writing | If the observer is in the air above the wheel, they will see nothing. | 2 |
| Drawing/Writing | Others | 4 |

Source: Survey data

Table 3 highlights the fact that eight students indicated a straight line as the trajectory of a point at the edge of the wheel's rim. Two other students wrote that if the observer is in the air above the wheel, he will see nothing, clearly showing confusion between the concepts of reference frame and trajectory.

Table 4 presents the patterns of student responses to situation 3, in which the observer changes reference point, observing a point at the edge of the front wheel rim and viewing the movement from the center of the car wheel.

Table 4 – Pattern of student responses to situation 3 in the “Building Hypotheses” section.

| **With response** | | **Number of students who chose the response pattern** |
|---|---|---|
| **Format** | **Content** | |
| Design | Car exiting through the right side | 4 |
| Writing | I would see everything spinning. | 6 |
| Design | Right suspension arrow | 3 |
| Writing | Stay still. | 2 |
| Writing | If the observer is at the edge of the rim, he sees the car moving in a straight line while simultaneously changing direction. | 2 |
| Drawing/Writing | Others | 4 |

Source: Research data.

In this situation, the student is expected to draw a circular path, with the observer at the center of the circle. However, as can be seen in Table 4, one student drew the expected path. However, he was classified as “Other,” since he did the same for all other situations in the hypothesis-building stage. Six students wrote that in this situation, the observer would see everything rotating, which is a reasonably consistent response with the expectation of a circular path.

Situation 4 best demonstrates the student's ability to abstract and relates this to the concepts of reference frame and trajectory planned in previous lessons. In this situation, the student will describe the trajectory of the center of the wheel rim with the observer positioned at the edge of the rim. Considering that the observer rotated around the center of the wheel, it was expected that the students would describe the trajectory of the center of the wheel as a circle.

In Table 5, it can be observed that seven students identified that the center of the wheel was rotating for an observer located at the edge of the wheel's rim, which may be associated with a circle. It was not possible to define rotating frames of reference in the open-source *software Tracker*, nor did we identify any possibility that any student considered the rotation of the frames of reference about themselves.

Table 5 – Pattern of student responses to situation 4 in the “Building Hypotheses” section.

| With response | | Number of students who chose the response pattern. |
|---|---|---|
| **Format** | **Content** | |
| Writing | Rotation | 7 |
| Drawing/Writing | Part of the car next to the left edge with the inscription “It's bigger” | 4 |
| Writing | The observer sees the car in motion. | 4 |
| Design | Spiral exiting through the right side | 2 |
| Drawing/Writing | Others | 4 |

Source: Survey data

In the “Preparing the Experiment” stage, students used the free software Tracker to construct the trajectories. The script provided instructions on how to select the video segment to be analyzed (video cut) and insert the measurement base, with the distance between axes, as a reference measurement for Tracker and coordinate axes.

In the “Taking Measurements” section, students received instructions on where to make the markings. Since the goal of the assignment was to compare trajectories in different reference frames, they were instructed to make markings at two points: at the center of the wheel (mass A) and at a point on the edge of the rim (mass B). To make these markings, the students used the mass point function of the track section of the software Tracker. The instructions for this step, according to the script, were: rewind the video to the beginning, position the cursor in the center of the wheel/rim edge, hold down the shift key and click on the point. This instruction was accompanied by images (Fig. 5).

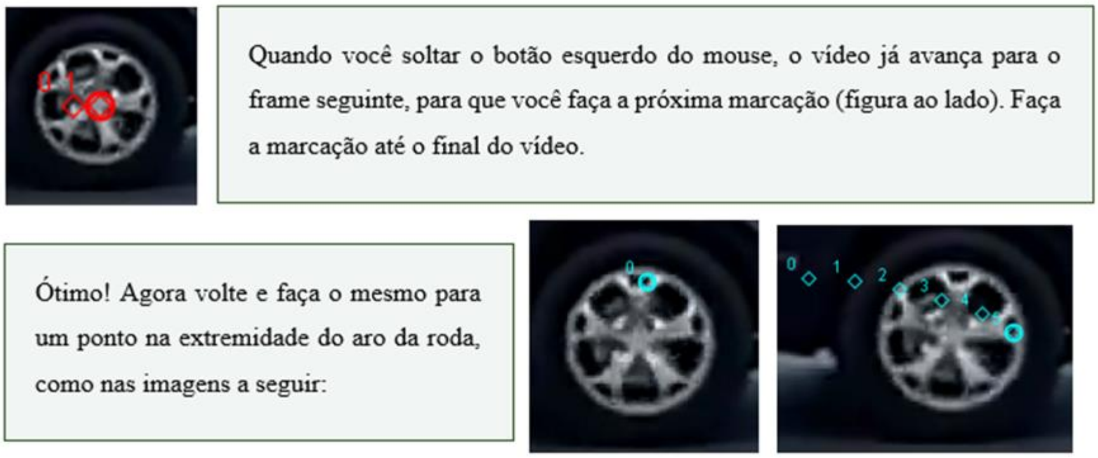


*Fig. 5 – Instructions on how to make markings on the front wheel.*

In the “Analyzing the Measured Data” stage, students needed to answer the questions based on three reference frame positions: (i) Reference Frame 1, shows that the observer is on the sidewalk [8](the coordinate axes are positioned in such a way that the axis $x$is on the wall separating the lanes of the highway and the axis $y$is aligned with a post), ( ii ) Reference Frame 2 shows the observer (the origin of the coordinate axes) over the center of the front wheel and ( iii ) Reference Frame 3 shows the observer positioned at the point on the edge of the wheel rim (Fig. 6).

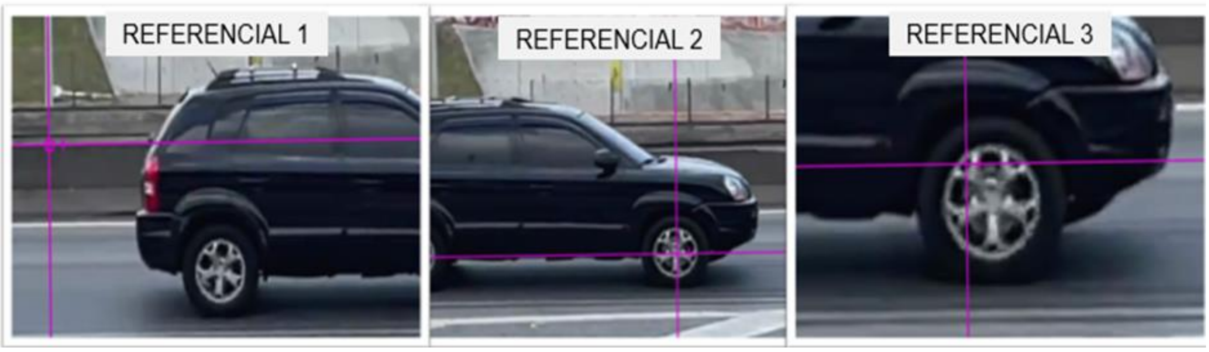


*Fig. 6 – Position of the origins of the coordinate axes in each reference frame.*

[8] For didactic purposes, we refer to the Earth's frame of reference as the sidewalk frame of reference.

The student should indicate the position of the reference frame for each situation before answering the questions about the trajectories of the marked points (masses A and B). Their answers are presented in Table 6.

Table 6 – Identifying the position of the reference frame in each situation.

| Answers | Reference 1 | Reference 2 | Reference 3 |
|---|---|---|---|
| Sidewalk | 2 | 9 | 4 |
| Center of the Wheel | 12 | 9 | 9 |
| Wheel rim end | 4 | 0 | 5 |
| White | 3 | 3 | 3 |

Source: Research data.

Table 6 shows that most students failed to correctly identify the reference points in situations 1 (sidewalk) and 3 (rim edge). However, approximately 43% of respondents correctly identified reference point 2 (center of the wheel), while an equal number stated that reference point 2 was on the sidewalk, and 3 students left the question blank. Observing the video analyses performed by the students, it is clear that none of those who marked “Sidewalk” or “Center of the Wheel” in Reference Point 3 marked a fixed point (that did not rotate with the wheel). Some marked the *lane* in the center of the wheel, along with the previous marking, and others did not. Obviously, there was no doubt in Reference Point 2 that it was not at the rim edge.

After identifying the reference point for the situation, the students were instructed to identify the trajectories of masses A (center of the wheel) and B (edge of the rim). To do this, they need to write or draw. In situation 1 (reference point on the sidewalk), the students need to draw the trajectories for the two masses. If the Tracker usage instructions were followed correctly, they would obtain a straight line (Fig. 7A) and a cycloid (Fig. 7B).

A crucial point in the analysis of the trajectories generated by the software lies in the configuration of the scales of the Cartesian axes. As observed in Fig. 8, the scale of the abscissa axis ($x$) is significantly larger than that of the ordinate axis ($y$). From the point of view of physical modeling, this exclusion is common in analyses of long-range movements with small vertical variations; however, from the perspective of semiotic transposition (Duval, 1993), it acts as interpretative noise.

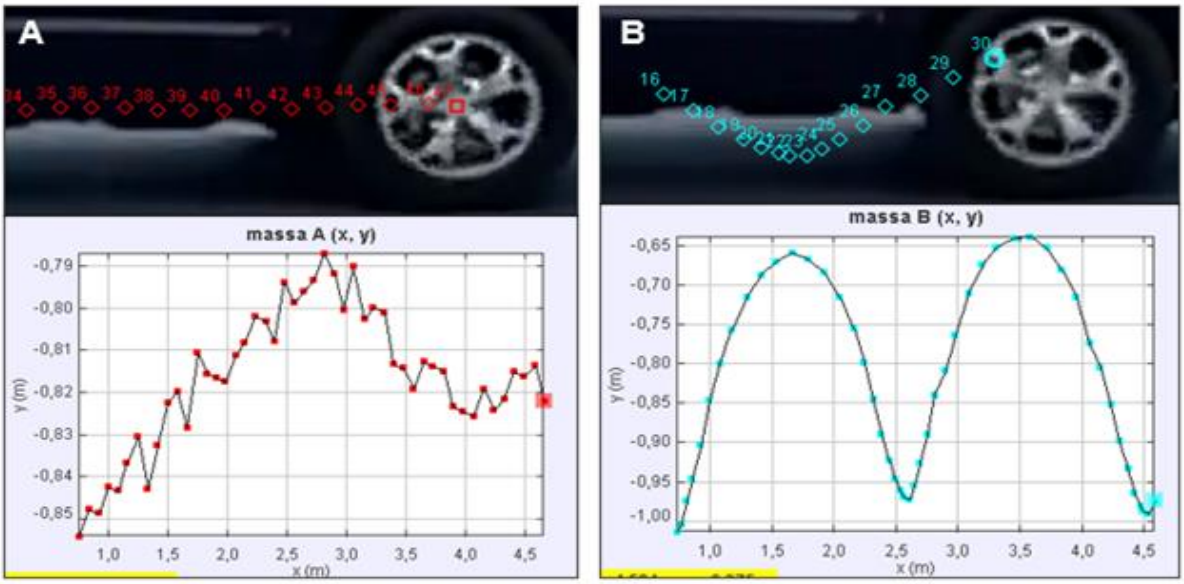


*Fig. 7 – Trajectory of point mass A (**A**) at the center of the wheel and of point mass B (**B**) at a point on the edge of the rim.*

When observing the center of the wheel (Mass A), the approximately 5 cm fluctuation - resulting from imperfections in the road surface or small vibrations in the filming - is visually flattened by the scale, reinforcing the prediction of a straight trajectory. However, for the edge of the rim (Mass B), a cycloidal trajectory, although mathematically correct, may appear less curved or 'flattened' on the screen. This statement suggests that the students' difficulty in transferring digital data to paper may not only be a failure of abstraction, but also a response to the literal reading of distorted visual data. As Cognitive Load Theory points out (Neto, 2023), the effort to mentally 'de-distort' the graph and reconstruct the real geometry of the movement (a classic cycloid or a perfect circle) imposes an additional challenge that many students with visual literacy gaps cannot overcome without direct mediation.

It is important to highlight that the identification of the trajectory of the center of the car's wheel as a straight line was contingent upon the students' perception, who could use either the diagram or the markings made with the track function in the video.

In the question involving mass A, most students drew a straight line. When students were asked to reproduce what they did in Tracker for mass B, two-thirds of the students drew a line relating the trajectory of mass B to a cycloid (Fig. 8) or a similar one (Fig. 9).

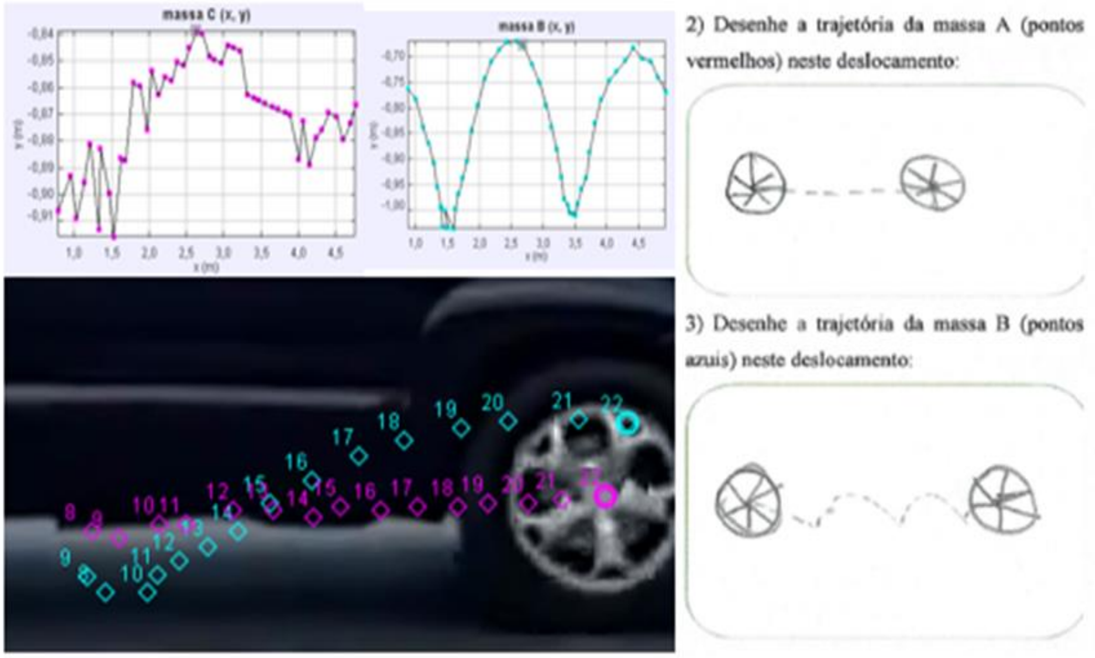


*Fig. 8 – Trajectories of mass points A and B and drawings made by student E12 for Situation 1.*

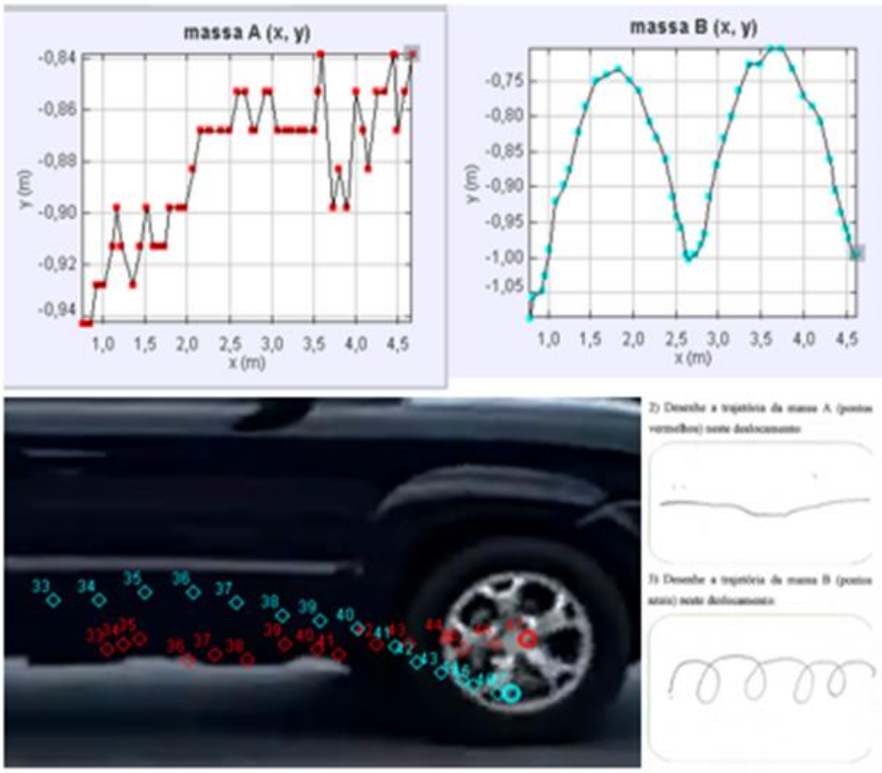


*Fig. 9 – Trajectories of mass points A and B and drawings made by student E15 for Situation 1.*

Comparing the trajectory of a point at the center of the wheel in the diagram with the markings made using the *track function* (image of the wheel) and the students' drawings raises the question of which screen the students observed when making their drawings: the diagram, because they considered the fluctuation of approximately 5 cm small enough to be unconcerned, or the screen with the markings in the image?

The way this task is structured makes it impossible to expect a discursive response, since it only requests a graphic record of the trajectory of the wheel's center, without requiring justification.

Although they did not correctly identify the reference point in Situation 1, most of the class agreed with some accuracy on the trajectories generated by the two points of mass.

For Situation 2, where the origin of the coordinate axes is at the center of the wheel (Reference Frame 2), half of the respondents marked the correct option (Table 6), but when they had to write the trajectory of mass A, which lies on the reference frame, only two students identified that it was a point (Fig. 10).

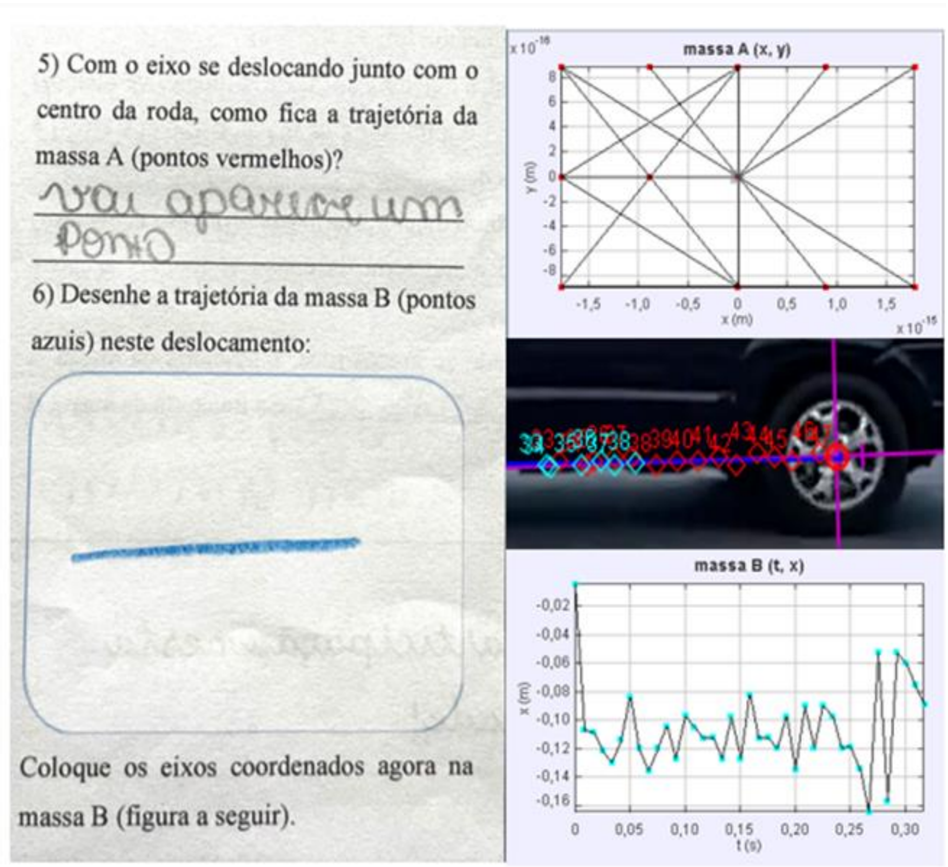


*Fig. 10 – Trajectories of mass points A and B and drawings made by student E20 for Reference Frame 2.*

In the trajectory of mass B, where students were expected to draw a circle, none of them managed to translate what they saw in the Tracker diagram onto the script.

Most students who got the questions about identifying the trajectory of mass B wrong in the center of the wheel frame also got the trajectories of the same mass wrong in the other two frames of reference. This may have occurred due to incorrect marking of the points on the edge of the rim.

In Reference Frame 3, the same situation was repeated: only the same two students identified that, when the reference frame is above it, the trajectory of mass B (point at the edge of the wheel rim) is a point. These same students, again, did not identify the trajectory of the mass as a circle.

Regarding Reference Frames 2 and 3, the students who correctly performed the video analyses were unable to translate them into the script, always reproducing what they saw in Reference Frame 1. This behavior may occur due to inattention to the fact that, in the trajectory diagrams of the observers moving along the reference frames (point A in Reference Frame 2 and point B in Reference Frame 3), the values for $y(m)$being on the order of $10^{-16}m$.

After the data analysis section, students were asked to fill in the blanks in a text comparing what they predicted before the experiment with what they observed during the experiment. Only eight students completed this part of the activity.

Table 7 presents a table with the students' responses to the gaps in the text of the “Building Conclusions” section.

Table 7 – Table of responses to the text in the Building Conclusions section.

| Código do Estudante | Revisitando Construindo Hipóteses | | | | | | | | Dados do Experimento | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Calçada | | | | Centro da roda | | Extremidade do aro | | Calçada | | Centro da roda | | Extremidade do aro | |
| | Centro da roda | Confirmou? | Extremidade do aro | Confirmou? | Extremidade do aro | Confirmou? | Centro da roda | Confirmou? | Centro da roda | Extremidade do aro | Centro da roda | Extremidade do aro | Centro da roda | Extremidade do aro |
| E11 | reta | sim | ondas | sim | trajetória circular | sim | trajetória espiral | sim | reta | onda | trajetória circular | trajetória espiral | (em branco) | (em branco) |
| E12 | reta | (em branco) | ondas | (em branco) | trajetória circular | sim | trajetória espiral | sim | reta | onda | trajetória circular | trajetória espiral | (em branco) | (em branco) |
| E13 | reta | (em branco) | ondas | (em branco) | trajetória circular | (em branco) | trajetória espiral | sim | reta | onda | trajetória circular | trajetória espiral | (em branco) | (em branco) |
| E16 | Calsada | Sim | Centro da roda | (em branco) | extremidade do carro | não | estrada | sim | reta | reta | reta | reta | reta | centro |
| E18 | Calçada | Sim | Centro da roda | Não | extremidade do carro | não | estrada | sim | reta | linha estranha | reta | estranha | reta | centro |
| E19 | caminho | sim | distância | sim | distância | sim | caminho | sim | distância | caminho | tempo | caminho | recordo | caminho |
| E20 | Linha reta | sim | ciclóide | sim | circunferência | sim | circunferência | sim | ciclóide | curva | ponto fixo | sem deslocamento | ponto fixo | circunferência |
| E21 | Linha reta | sim | ciclóide | sim | circunferência | sim | circunferência | sim | ciclóide | curva | ponto fixo | sem deslocamento | ponto fixo | circunferência |

Source: Research data.

Note in Table 7 that students E16, E18, and E19 used randomly selected words to complete the text. The responses from students E11 and E13, and E20 and E21 were similar because they conducted video analyses in groups of three and two, respectively. Student E12 completed the activity alone. Comparing the students' responses with their video analyses and scripts, the following inconsistencies were identified:

- In their initial predictions, students E11 and E13 expected a straight-line trajectory to a point at the edge of the rim (viewed from the sidewalk) and a rotational movement towards the center of the wheel (viewed from the edge of the rim). During the experiment, using the center of the wheel as a frame of reference, they consistently obtained a straight line for the trajectories from both the center and the edge of the rim. However, when analyzing the trajectory of the center of the wheel from the edge of the rim as a frame of reference, their observations diverged: E11 recorded waves, while E13 recorded a cycloid.

- Student E12 predicts that there is no reference point at the edge of the rim, and a trajectory from the center of the wheel would be a rotation. In analyzing the measured data, this student stated that there is no reference point at the center of the wheel, both the center of the wheel itself and a point at the edge of the rim describing straight-line trajectories, and that an observer at the edge of the rim would see the center of the wheel describing a straight-line trajectory and the edge of the rim as a cycloid;

- Students E20 and E21 predicted that all trajectories would be a straight line, except for the center of the wheel for an observer on the sidewalk, where they made random drawings. In the analysis of the measured data, they responded that the trajectory would be a straight line for a point at the center of the wheel (reference frame on the sidewalk) and at the edge of the wheel rim (both in the reference frame on the sidewalk and at the center of the wheel), and a "strange curve" for a point at the edge of the rim when this was the reference frame.

Researchers identified that the students in the study are accustomed to lecture-based classes, in which the teacher writes the lesson content on the board, the students copy it into their notebooks, and then there is an explanation of what was written. Access to the computer lab in the 1st grade occurs less frequently due to factors such as a scarcity of computers and limitations in teacher training for the use of technology. When these visits do occur, the dynamic tends to be traditional: teachers propose a research topic, and students are limited to transcribing the information from the screen into their notebooks. The researchers perceived that activities involving the development of student autonomy, careful observation, the importance of making notes, and the analysis of situations cause discomfort for the student, since they need to overcome inertia.

Furthermore, the researchers identified that the students studied had difficulties in reading and understanding the text, which highlights the need for a researcher to conduct a collective reading of the script, monitor what the students were doing, and provide guidance regarding any questions.

This change in routine also sparked interest and raised questions that generated interesting discussions. Of particular note is their familiarity with the area where the video was recorded, an area they know well, and their concern for the safety of the person who filmed it.

Finally, the logbook entries indicated that the students attempted to guess what the "correct answers" were, even though the instructors insisted they should reproduce what they saw, without there being a right or wrong answer. Records also showed the students' difficulty using computers and the various statements of "I don't know how to use a computer, only a cell phone," which contradicts Presnky 's (2001) concept of digital nativeism, but is justified by the observation that, according to the TIC Kids Online Brasil survey (Internet Steering Committee, 2024), approximately 93% of adolescents aged 15 to 17 surveyed. They stated that they did not own devices such as desktops or laptops. For the purposes of this research, in particular, the absence of these devices is justified, among other factors, by the fact that a family income of up to two months' worth of income corresponds to approximately 83% of families in the region[9].

The researchers also reported that it was necessary to disconnect the internet network because the students preferred to play games instead of performing the activity, as observed in Fig. 11.


*Fig. 11 – Student watching video (A and B) and playing on computer and mobile phone (C) during an activity.*

[9] https://www.data.rio/datasets/5c6396dc70594e4e849c61328c770fde_0/explore

In Fig. 11A, we have a student who, during an activity, watched videos on their cell phone (without muting the sound) even though they had been told they could not. In Figure 12B, we see that the video was not related to the content being discussed, and in Figure 12C, we have a student who was playing on the computer and switched to playing on their cell phone without bothering to exit the computer game.

Therefore, the decision to turn off the internet was made so that it would not become a source of distraction and evasion, both on the computer and on the smartphone, in order to ensure focus on the pedagogical objective of the research.

## V. Final considerations

This research allowed us to analyze the complex relationship between the use of video analysis, the POE methodology, and learning barriers in a context of socioeconomic vulnerability. By comparing theoretical sports with the practice observed in schools, conclusions emerge that challenge the idealized view of technology as an integrated solution for teaching Physics.

Firstly, the results demonstrate that the POE methodology (White; Gunstone, 1992), although powerful in elucidating cognitive conflicts, encounters the fragility of the students' scientific literacy. The difficulty in transferring the trajectory visualized on the Tracker screen (a phenomenological datum) to the graphic record on paper (a scientific datum) shows that semiotic transposition (Duval, 2009) is not an automatic process. Even in the face of the visual evidence of the cycloid, many students maintained the record of straight lines, which suggests that the “epistemological obstacle” of common sense is more resilient than a technological tool can, in isolation, promote a conceptual change.

Regarding the use of ICTs, research corroborates criticisms of the concept of “Digital Natives” (Prensky, 2001). It should be noted that students' familiarity with *smartphones* and social networks does not translate into competence for scientific modeling on desktop computers. The revelation that 93% of young people in this age group do not own computers at home – a fact reinforced by the TIC Kids Online survey (Internet Steering Committee, 2024) and the region's low IDS – explains the insecurity regarding specific software and the perception of the computer lab more as a space for leisure (games and videos) than for investigation.

The need to interrupt internet access to ensure pedagogical focus constitutes a relevant sociological fact regarding the theories of Cognitive Load (Neto, 2023) and Digital Distraction (Ramos; Vieira, 2020). In an environment saturated with stimuli for instant gratification, the attention required for the meticulous analysis of frames becomes a “scarce commodity.” For these young people, school ends up being a technological refuge, but the transition from this recreational use to academic use requires intensive teacher mediation, which goes beyond the content of Kinematics and involves the development of their own autonomy in reading and interpretation.

In short, the transition from phenomenological perception to scientific modeling in physics education is not a trivial process, and technology, while reducing the distance between the real and the abstract, introduces new semiotic challenges. An analysis of cycloidal trajectories in Tracker revealed that the interpretation of digital data is highly sensitive to configuration factors, such as axis scale, which can reinforce epistemological obstacles in students with low visual literacy.

Note that the student's “error” in drawing a straight line when a curve was expected may, in fact, be a literal interpretation of a visually presented graph, demonstrating that semiotic transposition (Duval, 2009) requires mediation that teaches the student to read beyond the screen. In addition, the socioeconomic context of the researched group demanded a reality in which the computer is an object foreign to the domestic routine of 93% of young people, making the school's computer lab a battleground between scientific curiosity and the refuge of digital entertainment.

It is concluded that the success of ICT interventions in peripheral public education depends on a careful look at Cognitive Load Theory (Neto, 2023). It is necessary that the act of teaching organizes the focus and deconstructs the immediacy of social networks, transforming the use of software into a tool for emancipation. This research reaffirms that, to achieve the competencies of the BNCC (Brazilian National Curriculum Base), Physics must be taught as a language for reading the world – an exercise that begins with observing cars on the Dutra Highway, but is only completed with the autonomy of the student's critical thinking.

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