ANALYSIS OF A TROLLEY MOVEMENT ON AN INCLINED PLANE USING WEBCAM ATTACHED TO RASPBERRY PI 3

Análise do movimento de um carrinho num plano inclinado usando uma Webcam acoplada a um Raspberry PI 3

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Abstract

The work consisted of filming the movement of a trolley descending an inclined plane without friction, using the stop motion technique through a webcam controlled by a Raspbery Pi computer. The research was applied to eleven Physics students from a federal university in Brazil, aiming to provide new teaching alternatives in basic education. The experiment was presented online, due to the sanitary restrictions of the pandemic by COVID-19, and consisted of exposing the themes necessary for understanding the activity, demonstrating the experiment, and applying a questionnaire. The results obtained in the questionnaire indicated the feasibility of using this teaching method and the verification of evidence of learning about what was explained. The activity carried out favored the investigation and modeling of the observed phenomenon.

Keywords: Stop motion; Rasperry Pi; Inclined Plane; Physics Education.

Resumo

O trabalho consistiu em filmar o movimento de um carrinho descendo um plano inclinado sem atrito, utilizando a técnica de stop motion através de uma webcam controlada por um computador Raspbery Pi. A pesquisa foi aplicada a onze alunos do curso de licenciatura em Física de uma universidade federal do Brasil, com o objetivo de oferecer novas alternativas de ensino na educação básica. O experimento foi apresentado online, devido às restrições sanitárias da pandemia por COVID-19, e consistiu na exposição dos temas necessários para o entendimento da atividade, demonstração do experimento e aplicação de questionário. Os resultados obtidos no questionário indicaram a viabilidade do uso desse método de ensino e a verificação de evidências de aprendizado sobre o que foi explicado. A atividade realizada favoreceu a investigação e modelagem do fenômeno observado.

Palavras-chave: Stop motion; Rasperry Pi; Plano inclinado; Ensino de Física.

1. Introduction

The advent of new technologies causes changes in society's behavior, bringing new perspectives to contemporary generations. The rapid growth in the use of Digital Information and Communication Technologies has shown potential for application in various areas of knowledge (Veraszto, Baião, & Souza, 2019; Esteves, & Silva, 2019; Rêgo, Silva, & Peralta, 2018). One of the consequences of using technological resources is the tendency that students must motivate themselves with the use of these methods in the classroom. This fact was already noticed by Kenski (1998), because, for him, new rhythms, and dimensions to the task of teaching and learning are imposed by the speed of technological changes. In this sense, simulators have been used in the teaching of Physics and are generally well evaluated by students, as can be seen in the works of Silveira, Junior, & Silva (2021); Silveira, Silva & Xanthopoulos (2020); Hadad, & Silva (2021); Santos, Reis, Santos, and Peralta (2019); Ayres, & Arroio (2015).

Physics seeks to measure quantities related to phenomena such as speed, temperature, magnetic field, etc., describing the reality of the system at a macroscopic or microscopic level (Einstein, 2006). The transposition of this to the school environment, by the teacher, will favor providing a great strategy to make students protagonists in the teaching-learning process (Freire, 2019a; 2019b).

The Tracker (2023) application is used to analyze movements, enabling tracking, and measuring of physical parameters in pre-recorded videos. The Raspberry PI (n.d.) is a single-board computer that can be utilized for various applications, such as home automation projects, media servers, control systems, games, etc. It offers connectivity features like Wi-Fi, Bluetooth, USB ports, and GPIO (General Purpose Input/Output), allowing the connection of external devices. The Raspberry PI can be equipped with a camera to record real-time videos and facilitate programming learning. Both approaches are complementary, providing a valuable learning experience.

In this project, we have chosen to use the Raspberry Pi instead of the Tracker application so that students can develop filming, programming, and basic electronics skills. To benefit from and apply this proposal, it is necessary to build learning objects that integrate the content of Physics disciplines with the use of Raspberry PI as a teaching resource. In this work, we will initially make a general survey about dynamic events, describing some characteristics and emphasizing the study of the movement of a trolley on an inclined plane, we will report the particularities of the use of stop motion as a didactic tool and, finally, we will show the properties of the experimental apparatus using these supports.

2. Theoretical foundation

In the pandemic period, remote learning was the solution to continue the school year, both in primary and higher education, in this period, in which we are still experiencing, the use of technologies, as educational tools, became essential for teaching-learning. Locatelli (2018) reinforces this thought, stating that teachers cannot neglect the use of various supports that the internet offers and that enrich classes.

2.1. Historical context of technology in education

In the 1940s, at the time of World War II, modern computers emerged. In the United States of America, in the 1960s, the microcomputer was popularized, and this became the main work tool. In the following decades there was the emergence of the internet, which corroborated with changes in the habits of global populations (Nicolaci-da-Costa, 2002). But education before this revolution caused by the internet, in the early 1970s, was perceived as a movement of information technology in education, in the administrative sector and in electronic information systems. In Brazil, the use of information technology came in the following decade through government resources (Tajra, 2018).

The use of computers in education, connected to the web, carried a range of possibilities for the development of innovative pedagogical practices, revolutionizing the education system. One of these possibilities is dynamic event modeling, which we will detail in the next topic.

2.2. Dynamic Event Modeling

When we observe a physical phenomenon, we can say that in most cases there is a dynamic, but in many cases, we are unable to describe it, as the act of measuring is compromised depending on the computational instrument. One way to overcome this difficulty would be to develop static representations of dynamic situations, associating, to the movement of interest, a model that would allow the student to follow the event and record the measurements.

Dias, Amorim and Barros (2009) used stroboscopic photography to make precise measurements of moving objects. The solution found, to facilitate the implementation of the technique, was to use a digital camera and a computer to access the Virtualdub (2021) and ImageJ (2021) software. Another way of modeling dynamic events is the use of video analysis software, where the most popular are ImageJ and Tracker, the latter being widely used in the field of science education (Bordin and Jr., 2019).

The main software and stroboscopic photography, video analysis, act in a similar way and follow the model described in figure 1. Initially, we have the event, which is the physical phenomenon, and which will be analyzed and recorded, in this way the variables can be controlled and allow the creation of representations, for example, in a body in free fall we can record time as a function of position and describe the movement from the point of view of Kinematics.

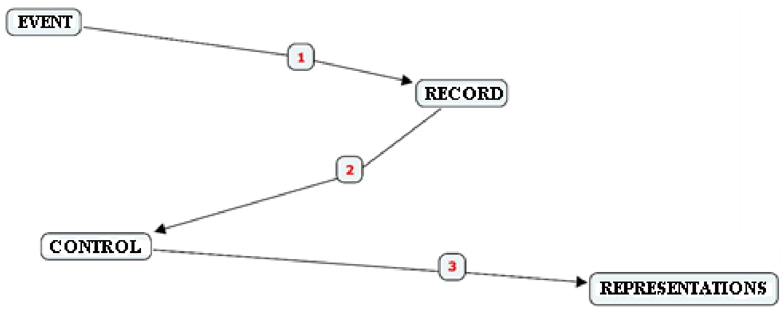

Figure 1: Order for model generation in video analysis and stroboscopic photography software.

The software that will be used will have the same function as the strobe camera and will analyze the movement of the descent of a trolley on an inclined plane (Dias, Vianna, and Carvalho, 2018), that is, a modeling via stop motion production.

2.3. Stop motion: features and applications

In the animation category, stop motion is characterized by using different sequential photographs of inanimate models to generate a type of event that simulates movement. The application of stop motion in cinema was a success (RODRIGUES AND LAVINO, 2020), it fitted very well in the film industry, over the years it became an extremely important teaching resource to describe physical, biological, and chemical phenomena.

The Common National Curriculum Base (BNCC) reinforces the idea of integrating science and technology in the classroom (Brasil, 2018), motivating teachers to use the materials that are available free of charge on various portals linked to the Ministry of Education (MEC), where we can cite the Theses and Dissertations Catalogs (Brasil, 2021), PhET (2021) - Physics Education Technology (Hadad, Junior, and Silva, 2018; Santana, Merklein, Sampaio, 2021) etc.

In this sense, we can state that there are several techniques that can be applied to facilitate the construction of knowledge by students, providing opportunities for new learning that restructure existing conceptual representations, such as Stop Motion video animations, which are part of the object of study.

2.4. Literature review

Data collection was done in the "Digital Library of Theses and Dissertations" (BDTD, 2021) and in the "CAPES/MEC Periodical Portal" (CAPES, 2021), between 2011 and 2021, enhancing the search for articles, which is a more common means of divulgation. Table 1 shows the keywords used in the filters, written in Portuguese and English, and the number of works selected in the search.

Table 1: Number of works used in the research.

Group	Subject matter	Number of articles used
1	Raspberry e stop motion ensino de ciências	3
2	Raspberry and stop motion science teaching	2

Table 2 presents basic information on the articles listed in Table 1.

Table 2: Basic data of the articles selected in the research.

Sequence	Reference	Title	Methodology used
1	Rodrigues and Lavino (2020).	Modelling in physics teaching via stop motion production with the Raspberry Pi compute.	Use of adapted animation for teaching fundamental concepts using Raspberry and stop motion.
2	Santos, Falcão, and Lima (2021).	The use of Stop Motion in teaching biochemistry to the middle level.	This work analyzes the production and application of animation videos via Stop Motion in a Didactic Sequence to operationalize the knowledge about aerobic cell respiration, which provided the opportunity to build scientific knowledge from the perspective of Meaningful Learning.
3	Corrêa, Martins, Millan, and Marangoni (2020).	A teaching experience through the Stop Motion Tool for teaching Atomic Models.	Working with the Stop Motion Cinematographic Technique with high school students, as an audiovisual resource and a pedagogical tool, addressing the didactic content "Evolution of Atomic Models"
4	Loukatos, and Arvanitis (2019).	Extending Smart Phone Based Techniques to Provide AI Flavored Interaction with DIY Robots, over Wi-Fi and LoRa interfaces.	This article reports the use of Raspberry and Arduino together with smartphone in the teaching-learning process for the formation of agronomy and agronomic engineering students. The article describes the steps of using certain types of programming for academic activities.
5	Vega, and Canãs (2019).	Open Vision System for Low-Cost Robotics Education.	This article shows an open code that simplifies the use of cameras in robotics to be applied in the classroom in the study of movement.

The articles cited in this literature review demonstrate the potential of technology and adapted animation to enrich the educational process, providing practical experiences and facilitating the understanding of complex concepts.

3. Methodology

The work had an investigative nature and a qualitative approach, from the construction of the experimental apparatus to the use of Stop Motion. This project was developed by a scholarship student of the Pedagogical Residency Program of the Physics course at a federal university in Brazil. This program is sponsored by the Coordination for the Improvement of Higher Education Personnel (CAPES) and aims to improve the training of teaching practice as of the second half of the course.

The research was presented to other scholarship students (also called residents) of the Pedagogical Physics Residency Program on 06.18.2021 and lasted one hour. The invitation was made on 06.14.2021 in a group of a social networking application to 24 residents, of which 11 participated. The scheduled activity had to be carried out by video conference, due to the sanitary restrictions of the pandemic. The practical activity was inspired by the article by Rodrigues and Lavino (2020), where an apparatus to produce stop motion animations that could be used in the teaching of Physics was exposed. For this, a Raspberry Pi computer with a built-in webcam was used, which enabled the reproduction of the modeled results.

The work used the experiment known as a linear air track, available at the University's Mechanics Laboratory, where the track was tilted slightly and a trolley that moved under negligible friction was released. The materials used were a monitor with HDMI input, a Raspberry Pi 3 Model B+ board, USB mouse, USB keyboard, USB Webcam (Logitech V U0018), USB type C source, HDMI cable, a micro-SD memory card (32GB) and linear air track (Phywe).

The presentation was divided as follows: I. Discussion of the problem of observing phenomena whose magnitudes vary over time. II. What would the Raspberry Pi be? III. Exhibition of a video explaining the principles of Quantum Physics applied to computer components (DoS, 2017). IV. Examples of using the Raspberry Pi. V. Comparison of the Arduino microcontroller with the Raspberry Pi. VI. Description of the materials used. VII. Steps for implementation. VIII. Code on the terminal. IX. Observed phenomenon. X. Collected data. XI. Conclusion. XII. Questionnaire.

Table 3 shows the codes entered (see item VIII above), in Linux, to trigger the Webcam operation when capturing data by the Raspberry Pi. In sequence 1, it is specified that the minicomputer store 30 images and that the camera takes 10 frames per second at a resolution of 1280x720 pixels and, in sequence 2, the data is recorded in the MPEG-4 standard which is used for digital video data compression.

Table 3: Linux commands typed into the monitor.

Sequence	Commands
1	streamer -t 30 -r 10 -s 1280x720 -o stopmotion00.jpeg
2	ffmpeg - start_number n -i stopmotion%d.jpeg -vcodec mpeg4 vídeo_stopmotion.avi

4. Results and discussions

Figure 2 shows the Raspberry Pi 3 minicomputer board used in the work. It consists of a 1.4GHz quad-core processor, 4 USB (Universal Serial Bus) inputs, Dual Band Wi-Fi connection (2.4GHz and 5.0GHz), Ethernet, Bluetooth 4.2, 1 HDMI (High-Definition Multimedia Interface) input and an SD memory card slot. The minicomputer and peripherals used on the day of the presentation can be seen in Figure 3.

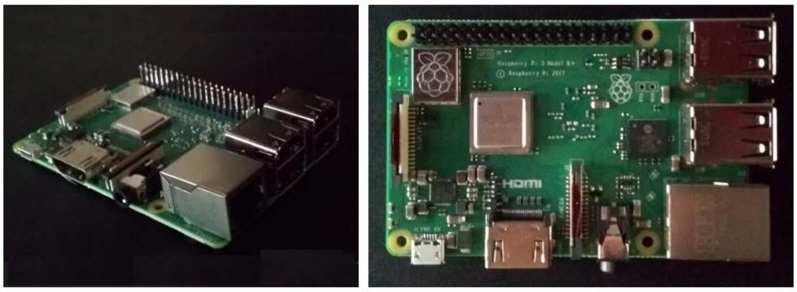

Figure 2: Photos of the Raspberry Pi Model B+.

Figure 3: Raspberry Pi, mouse, keyboard, monitor, and webcam used on the day of the presentation.

Figure 4 shows the images of (a) the linear air track in an inclined trajectory and (b) an enlargement of the trolley in the initial position. Commands in Linux were typed in the minicomputer terminal, see table 1.

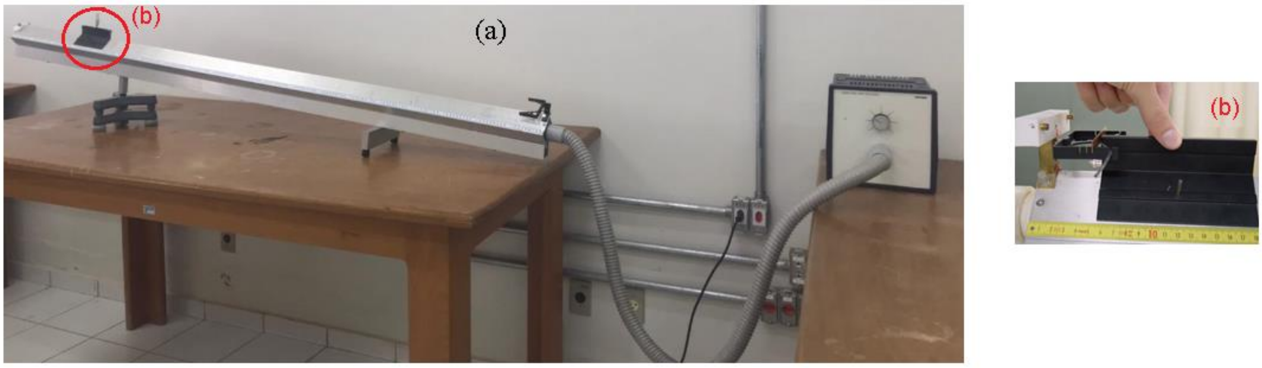

Figure 4: Photos of (a) linear air track on an inclined trajectory and (b) a magnification of the trolley in the starting position.

Images of the cart displacement, as a function of time, on the inclined linear air track were superimposed to explain the method of obtaining the measurements (figure 5). The origin of the trajectory was adopted when the trolley was at the highest end of the track, measurements started when it was released (zero initial speed). The time interval between each successive image was 1.0 s and the positions (x_1, x_2, x_3 etc.) were measured from the origin. To adjust the position measurements, it was necessary to work with scale, that is, relating the real size of the cart (12.8 cm) with the size of the images.

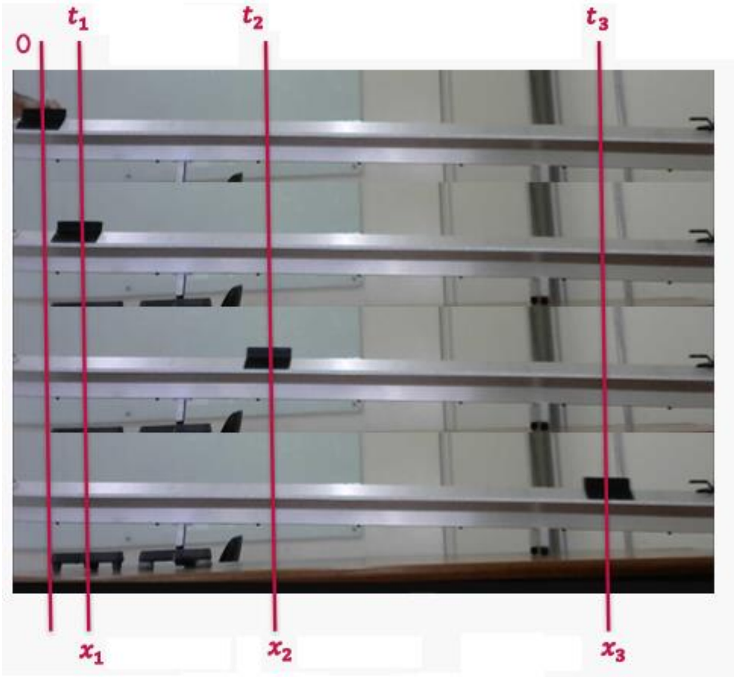

Figure 5: Superimposed images of the trolley moving on the linear air track.

The objective was to determine the type of movement and acceleration of the trolley, and for that, a graph of the position as a function of time was made (figure 6). The adjustment of the experimental points was performed by a polynomial function of order 2 in an electronic spreadsheet, demonstrating that the movement of the trolley was governed by the hourly equation of the position of the uniformly varied movement ($x = x_0 + v_0.t + a.t^2/2$, where x is the final position, x_0 the initial position, v_0 the initial velocity, t time, and a is the acceleration). By comparing the equation generated by the spreadsheet and the previous equation, the acceleration of the body was calculated, that is, a = 0.398 m/s^2.

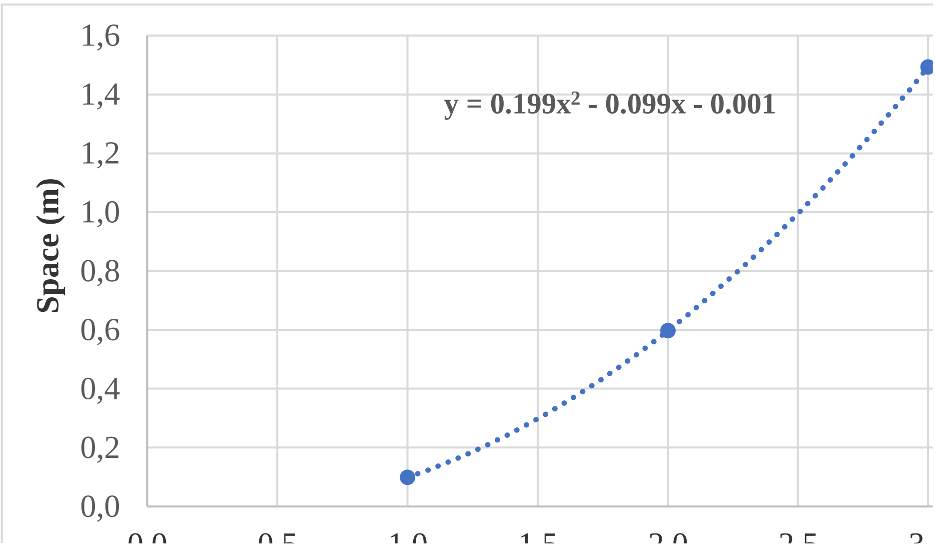

Figure 6: Graph of trolley position as a function of time and the respective adjustment of points by a 2nd degree equation.

The acceleration of the trolley was also calculated using the sine of the inclination angle of the track and ignoring friction, as it moved under an air flow (figure 7) in position 2. Using Newton's laws, the acceleration of a body moving on an inclined plane without friction is given by a = g.senθ and, in this case, considering g = 9.8 m/s^2 the acceleration resulted in a = 0.480 m/s^2.

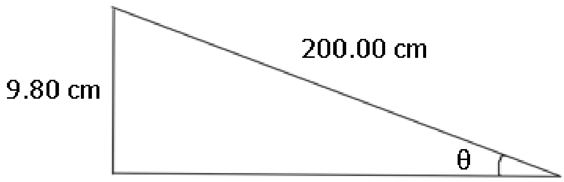

Figure 7: Diagram illustrating the measurements taken to calculate the sine of the angle θ of inclination of the linear air track.

The comparison between the two accelerations was performed by calculating the percentage error, which resulted in 17.1%. The difference between the results was probably due to the perspective of capturing images from the webcam, which generated a type of distortion, the time taken to capture the images by the webcam and the existence of friction, albeit low, but which may have interfered with the determination of physical quantities.

Table 4 shows the questionnaire used to assess evidence of participants' learning at the end of the presentation. The questions and answers obtained were displayed and captured in an electronic form.

Table 4: Questionnaire applied.

Presentation Questions - Analysis of trolley movement on an inclined plane using a webcam attached to Raspberry Pi 3
I am aware of and agree to participate in the mentioned study. I affirm that I was duly informed about the research objectives, the procedures to which I will be submitted, and the possible risks involved in my participation. The person responsible for the ongoing investigation assured me of any additional clarification, which I may request during the investigative process, as well as the right to withdraw from participation at any time that suits me, without such withdrawal entailing risks or harm to my person and my family members, and the anonymity and confidentiality of the data relating to my identification is guaranteed. I am also aware that my participation in this investigative process will not bring me any economic benefit.
1. The Raspberry Pi is an interesting option that can be used in teaching Physics. Would you use this device in the classroom? ( ) I totally disagree; ( ) I partially disagree; ( ) Indifferent; ( ) I partially agree; ( ) I totally agree.
2. The Raspberry Pi only works if it is connected to a computer via a USB cable, like the Arduino microcontroller. ( ) True; ( ) False.
3. On the Raspberry Pi board there is an integrated memory module, eliminating the need for an external memory card. ( ) True; ( ) False.
4. In the demonstrated experiment it was possible to visualize the Physics involved. The difference between the acceleration value obtained by the filming and the acceleration value obtained by calculating a = g.senθ was probably caused by the influence of the viewing angle as a function of the positioning of the webcam, which displayed the images in a way distorted. ( ) True; ( ) False.
5. Write, in your opinion, what would be a possible solution to solve the case reported in the previous question, that is, regarding the display of distorted images?

Figure 8 shows the answers given to the first four questions in the questionnaire in table 4. In question 1, everyone agreed with the use of the Raspberry Pi in the classroom, although a little more than a quarter partially agreed. The majority got question 2 right, which is true, while in question 3, which is false, there were only 27.3% of correct answers. The Arduino is much better known than the Raspberry Pi and the first one must be connected to a computer's USB port, unlike the second one, which has its own processor, justifying a better result of correct answers in question 2. Question 3 points to a possible inattention to what was said by the presenter and as mentioned earlier, the Raspberry Pi was not a device familiar to the participants. All of them got question 4 right, considering that they realized the problem of viewing the images when measuring the position of the cart, which was well emphasized by the presenter.

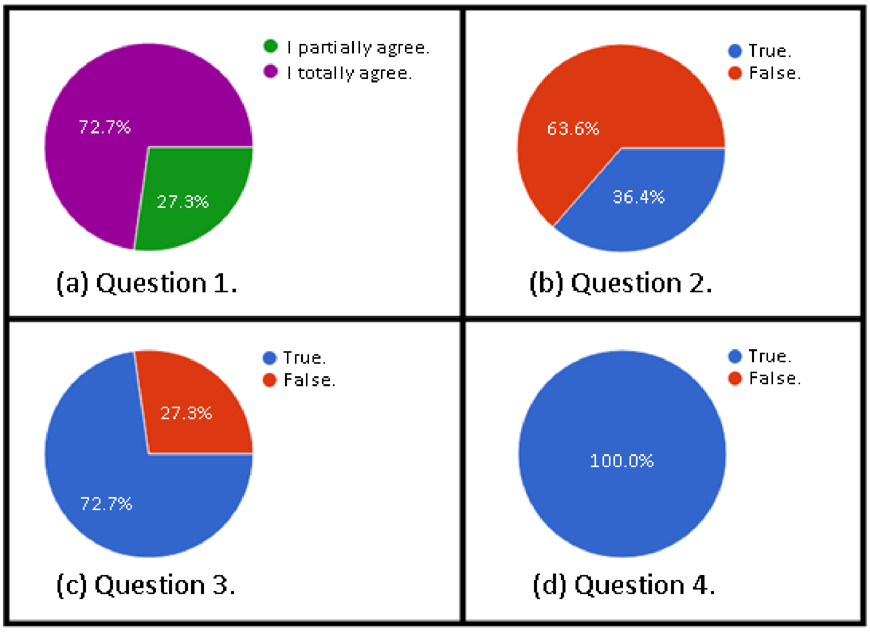

Figure 8: Answers given to questions 1 to 4 of the questionnaire (Table 4).

Table 5 shows the responses written by the fellows in question 5 of the questionnaire in table 4. 36% of the scholarship students said that the position of the webcam should be changed, 9% thought that the webcam should be brought closer to the assembly, 27% defended the repetition of the experience, 27% that a better-quality camera should be used and 18% said they did not know. The sum of the percentages was greater than 100% because some wrote more than one solution. Analyzing in general, it was possible to notice that almost all (82%) indicated viable solutions regarding the problem of visualization of image distortion, only participants 5 and 8 (18%) did not want or did not know what to say.

Table 5: Answers given to question 5 of the questionnaire (Table 4), they were transcribed in full and placed in quotation marks.

Participant	Answer
1	“Changing the position of the Web Cam”
2	"A camera with higher frames per second capture"
3	"I would improve the viewing angle"
4	"A better positioning of the webcam, and enlargement of the images"
5	“I don't know, if I were I would repeat it until they are not distorted, 'laughs' ".
6	“I have no idea. I don't know about that part"
7	"Perhaps do it more than once, so more observations could be made and thus fewer errors possible"
8	“Nothing to declare”
9	"A possible solution in this case would be to look for the best angle to obtain the images or to look
10	“Maybe move the webcam closer to capture more accurately”
11	"Use a camera more efficiently, and if possible, repeat the experiment more than twice"

In Rodrigues and Lavino's (2020) proposal, the production of stop motion was developed to animate the kinematic variables of simple harmonic motion, projecting the magnitudes of the uniform circular motion of a particle on one of the axes, whose discussed example is part of the Physics content from high school. The works by Santos, Falcão and Lima (2021) and by Côrrea, Martins, Millan, and Marangoni (2020) also used the stop motion technique, differentiating in the contents that are from other disciplines (Biochemistry and Chemistry, respectively) and the participants were from high school. In our work, a trolley was shot down an inclined plane, ignoring friction.

Although the two activities mentioned in the paragraph above used the same stop motion technique, they differed by the types of practices, when compared to our work. Both involved planning the physical model, the frames and capturing them, while ours involved investigating the physical phenomenon (the trolley going down an inclined plane) through filming.

Loukatos and Arvanitis (2019) developed a project for students to improve the construction of the DIY robotic vehicle and the Raspberry Pi was used as a platform. Similarly, Vega, and Cañas (2019) used the Raspberry Pi to build a robot, coupled to a PiCam camera, which had its use simplified through the application of an open code. In our work, the Raspberry Pi was used to take and record the sequential photos necessary for the generation of stop motion.

5. Final Considerations

We show a proposal for the didactic use of an experimental apparatus that can capture the reproduction of stop motions, one of the advantages of this apparatus is that it was built with a low-cost computer using free software, developed specifically for the function.

The experiment expands the possibilities of modeling, allowing students to achieve autonomy in the teaching-learning process, significantly supporting their training. By doing this, the student activates their knowledge, refining their conceptions about the animate phenomenon.

Although the experiment was applied under non-ideal conditions due to the restrictions imposed by the pandemic, that is, remotely, its application in the classroom was shown to be feasible by the testimonies of the participants. It is certainly an interesting option to be used in the analysis of movements, both from the point of view of experimental visualization and in the mathematical modeling of the phenomenon.

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