revista Observatório

e-ISSN nº 2447-4266
Pslmss, v. 11, n. 1, 2025
http://dx.dxy.xrg/10.20873/hft.2447-4266.2025v11n1a05en

USING THE CONCEPT OF FREE FALL AS A MOTIVATION TO STUDY NATURE

O USO DO CONCEITO DE QUEDA LIVRE COMO MOTIVAÇÃO PARA ESTUDAR A NATUREZA

CÓMO UTILIZAR EL CONCEPTO DE CAÍDA LIBRE COMO MOTIVACIÓN PARA ESTUDIAR LA NATURALEZA

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Received on: 11.12.2025
Accepted on: 03.01.2025
Published on: 06.03.2025

ABSTRACT

This paper reports on the methodology used to improve the understanding of high school physics content relating to free fall. Using simple experiments that made it possible to measure the time taken for a steel ball to fall, it was possible to strengthen understanding of the concept in question (free fall). Five stopwatches were randomly distributed among the students, who recorded the time taken for the sphere to fall, repeating the activity 16 times. The approach, although still inexpressive compared to the possibilities that the apparatus can offer, was relevant because it aroused the interest of most of the students. To comment on cognitive development and problem-solving skills, stimulation of analytical thinking, and the ability to face more complex challenges, it is essential to explore the apparatus and theoretical aspects further.

KEYWORDS: Free fall; Gravity; Nature.

Introduction

The difficulty of learning physics, especially about understanding concepts and their applicability in everyday life, is a significant challenge for students and educators. As a science, physics plays a crucial role in explaining natural phenomena and underpinning many technologies that permeate our daily lives. However, the abstract nature of many of its concepts, coupled with a teaching methodology that sometimes fails to bridge the gap between theory and everyday applications, can result in a perception that physics is inaccessible or irrelevant to humanity. Thus, there is a need

e-ISSN nº 2447-4266
Pslmss, v. 11, n. 1, 2025
http://dx.dxy.xrg/10.20873/hft.2447-4266.2025v11n1a05en

for innovation in physics teaching methodology with new methods that should emphasize the importance of conceptual understanding, fostering scientific reasoning and research and development (Bao & Koenig, 2019).

Teaching physics through laboratory experiments offers several benefits for students and for the learning process as a whole (Bonadiman & Nonenmacher, 2007). These include: applying theoretical concepts learned in the classroom to real-world situations, helping to solidify their understanding; and the possibility of developing a deeper and more intuitive understanding of physical principles, which can be more difficult to achieve through theoretical approaches alone. By carrying out laboratory practice, students develop skills in collecting and organizing data, and because they feel involved in the educational process, they are perhaps more motivated and can develop creativity and criticality more openly (Botelho, 2020).

Most of the time, students may not have learned physics because they weren't given experimental lessons, for a variety of reasons, including overworked high school teachers with no time for planning, the lack of technicians to help organize experiments, and the lack of adequate physical space in schools to store equipment and carry out practical lessons. It should be noted that in 2023, state schools in the state of Tocantins received several Physics laboratory items with potential for teaching and learning the content of this subject. With the possibility of implementing simple experiments, students can be motivated to take an interest in learning physics and better understand natural phenomena in their daily lives. It is the methodology that the teacher adopts to approach the content that can arouse interest in Physics, favoring a positive image of it and providing learning (Bonadiman & Nonenmacher, 2007). This simple pedagogical intervention aims to analyze the possibility of including laboratory practices in Physics classes and encourage learning the subject's concepts.

We decided to set up equipment and carry out a free fall experiment. Free fall is the concept developed during the teaching and learning of Newton's Three Laws, which describe the behavior of bodies in motion and are the basis of Classical Mechanics. These laws were formulated by British physicist and mathematician Isaac Newton in the 17th century and are considered one of the greatest achievements of classical physics (Hewitt, 2000).

Newton's first law, also known as the law of inertia, states that an object at rest will remain at rest and an object in motion will remain in motion with constant velocity unless an external force acts on it, i.e. if the sum of the forces on a body is zero the body is an inertial reference point. Newton's second law states that a mass subjected to

e-ISSN nº 2447-4266
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a non-zero resultant force acquires an acceleration in the same direction as the resultant force. In other words, this law allows us to relate the force applied to an object to its response in terms of acceleration. Also, it can be said that force is the variation of linear momentum. Newton's third law is known as the law of action and reaction. It states that for every action, there is always an equal and opposite reaction applied to different bodies. This means that when one object exerts a force on another object, the second object exerts a force of the same magnitude and opposite direction on the first object (Godoy, Agnolo, & Melo, 2020, p. 46), or as Ramalho et al. (2009, p. 190) writes, "the mutual actions of two bodies, one on the other, are always equal in the module, but in opposite directions".

Newton's three laws are of fundamental importance in physics and are applied in many areas, from the movement of celestial bodies to the construction of bridges and buildings. They are also the basis for the development of other areas of physics, such as quantum mechanics and relativity (Doca, Biscoula, & Bôas, 2012). Newton's laws offer accurate predictions of the movement of bodies, regardless of their size or complexity. However, they lose validity for very small bodies, in quantum physics, or for bodies at high speeds, in the theory of relativity.

The physical laws introduced by Newton are the basis of all classical mechanics and are based on experimental observations that led to the aforementioned statements. These laws can be understood as postulates dictated by nature. If their implications, and all the theory built up from them, also agree with the observations of nature, then these postulates can be consistently accepted as true. Therefore, they take on the category of physical laws, i.e. truths manifested by Nature itself (Fitas, 1996, p.4). Free fall is an important phenomenon explained by Newton's laws that describes the movement of a massive body under the exclusive influence of the Earth's gravitational force. According to the laws of free fall, all objects, regardless of their mass, accelerate toward the ground at a constant rate due to gravity. This acceleration is known as the acceleration due to gravity and is approximately equal to 9.8 m/s^2. The speed of an object in free fall increases uniformly over time, while its position relative to the starting point is described by a quadratic function of time. Free fall is a fundamental concept for understanding a variety of natural phenomena and is often applied in fields such as physics, engineering, and astronomy (Hewitt, 2000).

It should be noted that Lev Vygotsky, author of the theory of cultural-historical learning, in one of his works, encourages the use of experiments in the educational context. Although he does not deal specifically with experimentation as a teaching

e-ISSN nº 2447-4266
Pslmss, v. 11, n. 1, 2025
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method, he explores the relationship between cognitive development and social learning, underpinning the idea that learning occurs more effectively through social interaction and active engagement with the environment, elements present in experimental activities (Vygotsky, 1986).

For Vygotsky, the concept of learning is related to two zones of development: the zone of actual development and the zone of proximal development (ZDP). The ZDP is understood as the distance between the level of actual development, which is usually determined by solving problems independently, and the level of potential development, determined by solving problems under the guidance of an adult or in collaboration with more capable companions (Vygotsky, 1984). Thus, the teaching and learning process must be organized with the student's zone of potential development in mind, so that it is efficient and promotes their intellectual evolution (Costa, 2006).

Therefore, as Olson and Loucks (2000) suggest, we performed an experimental procedure that takes into account the students' ZDP, in an appropriate manner to the concept of free fall. Our approach required data collection and organization, with students' discussion in groups for stimulation of critical thinking, to promote our main objective, that is, to motivate students to study nature.

Methodo

This investigation consisted of a teaching and learning strategy, based on Vygotsky's cultural-historical theory (Costa, 2006) and on the investigative approach involving experimental activities with physical laboratory material that schools of the State of Tocantins received at the end of 2023.

These schools received a box labeled "Free Fall Set". Their items were checked and the experiment was tested before use. Our planning favored an open space in the school that could accommodate all the students, but to be sure, initially, it was tested in the classroom, in open spaces, in laboratory environments, and in the common classroom, all tests altogether with the class teacher to identify the best environment to carry out the activity with the selected class. The time was organized within the Physics class schedule and duration, which was one hour and 50 minutes per week. After the tests, we opted to use the school's open area.

Although the project does not specifically deal with experimentation as a teaching method and does not have the illusion of exploring the relationship between cognitive development and social learning in such a short space of time, based on the idea that learning occurs more effectively through social interaction and active

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engagement with the environment, elements present in experimental activities (Vygotsky, 1986), the aim is to assess how experimental practice can stimulate students to enjoy studying physics subjects.

The box is a SIRUS educational kit, which contains 3 steel spheres, one weighing 14g, 23g, and 33g. We used the latter in this work. There were 5 chronometers which were randomly distributed among the students. The assembly was carried out in the presence of the students and followed the instructions in the manual that came with the SIRIUS kit. There was a brief dialog between the teacher and the students, helping them to think about the masses of the spheres and the time it took them to fall.

We tried to identify sources of difficulty in the lessons to improve the mechanisms that help students learn physics (Júnior, 2020). We used the methodology known as the Investigative Teaching Sequence, which is essentially a pedagogical approach that emphasizes the active participation of students in the construction of their knowledge. It is based on the principle that students learn best when they are involved in practical and challenging activities in which they have to investigate, explore, and solve real problems.

The Investigative Teaching Sequence follows a step-by-step structure, starting with the presentation of a problem or a challenging question that arouses the students' curiosity, very much in line with what we have designed in our practices. Students are then guided to formulate hypotheses, make predictions, and draw up action plans to solve the proposed problem. They are encouraged to carry out investigations, collect data, analyze results, and draw conclusions.

An important feature of this methodology is the teacher's role as a catalyst for learning. They provide guidance, ask stimulating questions, promote group discussions, and provide resources to support the students' investigations. The Investigative Teaching Sequence aims to develop not only subject-specific knowledge but also expected to develop cognitive skills such as critical thinking, problem-solving, communication, and teamwork. In addition, it seeks to promote student interest and motivation, making learning more meaningful and lasting. The benefits of the Investigative Teaching Sequence include the development of research and data analysis skills, the promotion of critical thinking and creativity, increased student motivation and engagement are also objectives of this methodology that we adopt, as well as preparation for solving real-world problems. The Investigative Teaching Sequence methodology is, in short, a pedagogical approach that puts students at the center of the

e-ISSN nº 2447-4266
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learning process, encouraging them to investigate and solve problems. Above all, it aims to develop cognitive skills and promote more meaningful learning.

The methodology adopted structures learning in clear, interactive stages. This methodology promotes a dynamic learning environment where students are encouraged to actively explore and solve real problems. Below are the detailed steps of the strategy adopted for the free fall experiment, a fundamental topic in the study of physics.

Step 1: Preliminary questions

1. Proposed problem: The initial question presented to the students was about free fall, a physical phenomenon where an object is dropped from a certain height without initial impulse, moving under the influence of gravity.

2. Awakening Curiosity: The students were challenged to think about what affects the speed and time of an object's fall.

3. Formulating hypotheses: From the initial questioning, the students wrote down as many hypotheses as possible about the factors that could influence the fall of an object, such as mass, air resistance, and the height of the fall.

Step 2: Demonstration:

Material used

1. Digital stopwatch to measure fall time.
2. Ruler or tape measure to measure the height of the fall.
3. A sphere to test the fall time.
4. SIRIUS sensors capture the fall time of the steel ball in the experiment, allowing for detailed analysis afterward.

Experiment steps

1. Preparation: Setting up the equipment where the objects would be dropped from different heights.

2. How it was done: The students dropped objects of various masses and recorded the time taken for them to fall using a digital stopwatch.

3. Data collection: Use of the Lan one-dimensional vector method in MATLAB software to process the data collected.

4. Data Analysis: The data was entered into graphical analysis software, where graphs were created to visualize the relationships between mass, height, and fall time.

Step 3: Discussion and Conclusion

After carrying out the experiment and analyzing the data, the students discussed their initial hypotheses. The hypotheses were compared with the experimental results. For example, whether the fall time was shorter or longer than expected. The students came to conclusions based on the evidence collected, gaining a better understanding of the principles of free fall and the impact of different variables on the process of the sphere falling.

Intervention Steps

1ST MOMENT

Dialogue between teacher and students, presenting the activity to be carried out, its objective, and the content involved, highlighting the physical quantities involved. The teacher then poses the guiding question for the intervention: "If you drop objects of different masses from a certain height, do they hit the ground at the same time?" and asks for hypothetical answers.

2ND MOMENT

Presentation of the experimental apparatus and suggestions from the students on how to experiment. Once the suggestions have been accepted, the teacher selects one of them, the one that helps to answer the initial question, and they discuss how to carry out the activity. The teacher comments that he has 5 analog stopwatches and asks five students to help him use these measuring instruments during the fall of the sphere with the largest mass. The teacher asks a student to carefully drop the 33g sphere from the same height while the time measurements are taken and five other students record the data produced. The experiment is repeated several more times, including with the other two spheres of smaller and different masses.

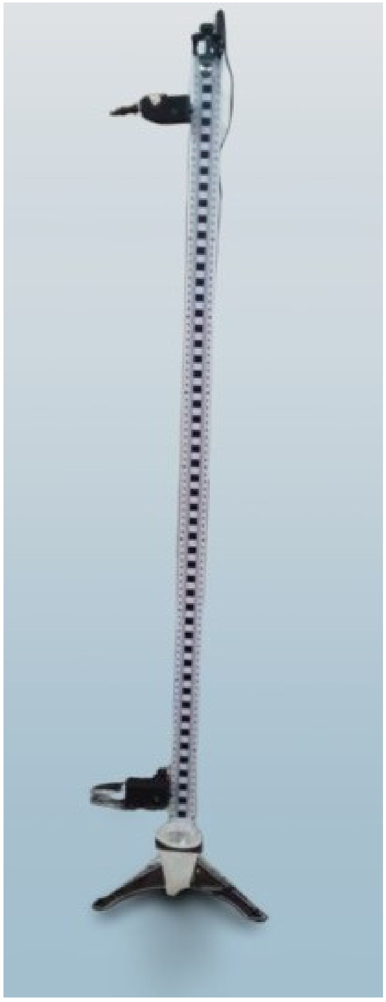
3RD MOMENT

The arithmetic averages of the times collected by each student are calculated and then the average of the averages is calculated, giving a single value. Finally, they experiment with the sensors, the solenoid (used to fix the ball and let it fall from the same height in all repetitions), and the digital stopwatch several times, take the average, and compare it with the value obtained previously using the analog stopwatches.

e-ISSN nº 2447-4266
Pslmss, v. 11, n. 1, 2025
http://dx.dxy.xrg/10.20873/hft.2447-4266.2025v11n1a05en

Figure 1, shows the experimental apparatus made up of a graduated vertical rail with a tripod; four sensors; a solenoid, a basket, a plumb bob, and a steel ball with a mass of 33g, used in this investigation.

Figure 1
Vertical rail for free fall experiments



Source: The authors, on 15/05/2023.

Results and Discussion

The teacher asked the students to read the content of free fall from the text by Ramalho (2009) beforehand. As a result, the lesson began with the students' expectations, since they would be using one of the devices in the Multifunctional Kit

e-ISSN nº 2447-4266
Pslmss, v. 11, n. 1, 2025
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delivered to schools by the Tocantins State Department of Education (SEDUC) for the first time, and the teacher followed the intervention steps presented by the researcher.

We proceeded as planned, starting with a dialog between the students, with the guiding question and the hypothetical answers, which had few variations about the falling time, i.e. that the one with the greatest mass would reach the basket first. Sixteen (16) throws were then made with the 33g ball and five student volunteers measured the ball's fall time, using an analog stopwatch, and the simple average of these measurements and the average of the averages obtained were taken. Mathematical software (MATLAB) was used to create a vector, LAN1x16, as follows: LAN= [34 35 25 34 33 39 41 38 55 34 65 53 28 40 47 31]. This vector was then divided by 100, L=LAN/100, to obtain the real value of the fall of the sphere in seconds, which resulted in eighty measurements. The average time obtained by the students in the first moment using the analog chronometers was 0.4s for approximately 90cm of free fall. After five more launches with the sensors, solenoid, and digital stopwatch attached to the vertical rail, an average fall time of 0.33s was obtained. It should be noted that the value obtained theoretically was 0.29s.

The students were encouraged to critically analyze the results obtained during the experiments, comparing them with theoretical expectations and identifying possible errors or sources of inaccuracy (Freire, 1996). Considering an approximate error of (±1) for the average obtained with analog chronometers, the values of 0.39s and 0.31s were obtained, showing a distance of 13.4% from the theoretical value and about the second moment of the activity with measurements using a more precise instrument (digital chronometer), considering an error of (±1), 0.32s and 0.34s were obtained, 11.7% off the theoretical value.

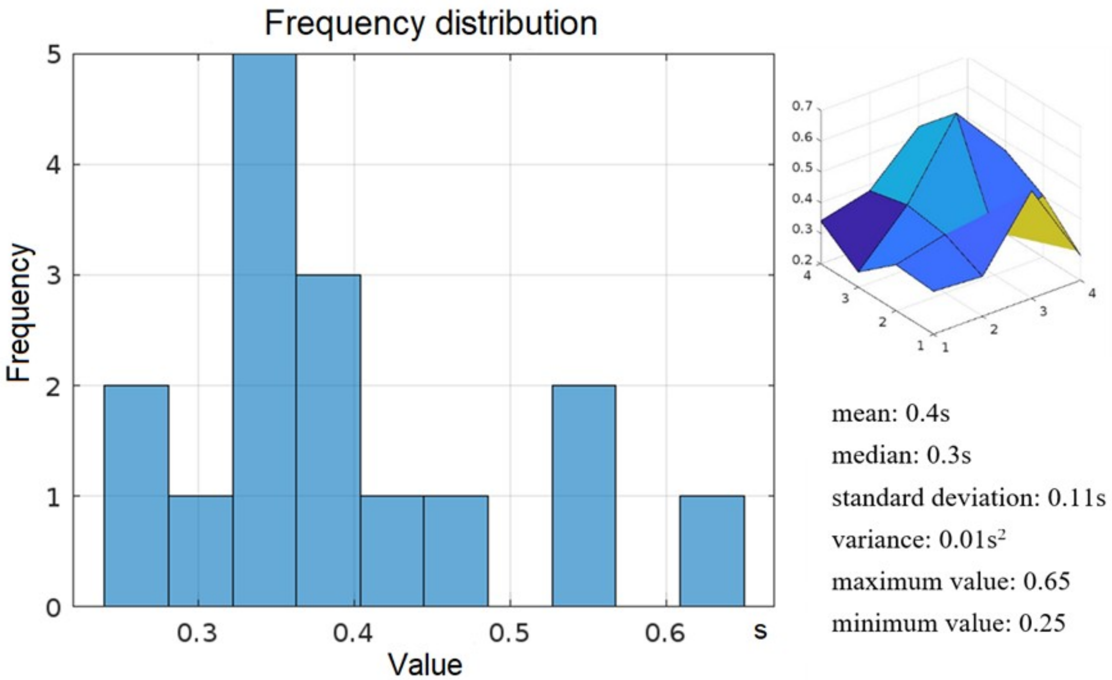
So, with values that were relatively small deviations from the theoretical value, given the imprecision of the measuring instruments used, it was possible to verify the students' motivation and also the identification of theory in practice. The frequency distribution for the sixteen launches, which are the averages of five random measurements made by the students, is shown in Figure 2.

revista Observatório

e-ISSN nº 2447-4266
Pslmss, v. 11, n. 1, 2025
http://dx.dxy.xrg/10.20873/hft.2447-4266.2025v11n1a05en

Figure 2

Frequency distribution for the sixteen launches of a 33g sphere. The figure also shows a 4x4 matrix for the data in surface form and the results for mean, median, standard deviation, variance, maximum value, and minimum value.



Source: The authors.

This pedagogical approach not only facilitated the understanding of physical concepts but also developed some essential skills such as critical thinking, data analysis, and teamwork, preparing students to solve more complex real-world problems.

Analysis of the results

Good results in classes can only reflect meaningful learning and infers the development of skills, student commitment, and an understanding of the application of physics in everyday life. This may show that laboratory practices have fulfilled their role in providing a better-quality education, perhaps improving the quality of life for everyone, because we can live better if we better understand the nature that surrounds us. As far-reaching results, we can mention that it is likely that the enrichment in the understanding of concepts, the development of some practical skills, the stimulation of critical thinking and problem solving, as well as an improvement in the motivation to study was obtained with the students, a fact inferred by the enthusiasm of the majority of the students. Of course, some weren't interested in the problem, which could lead to further discussions on how to capture young people's imagination about natural

e-ISSN nº 2447-4266
Pslmss, v. 11, n. 1, 2025
http://dx.dxy.xrg/10.20873/hft.2447-4266.2025v11n1a05en

phenomena. In the relaxed atmosphere in which the lessons were carried out, it can be inferred with reasonable probability that the vast majority of students accepted these methods. The students followed the instructions as closely as possible. Most of the class followed the results and interacted with the launches, showing that an interactive activity with the students can help learning.

The problem presented to the students was to investigate the principle of free fall, with the specific aim of verifying that the fall time of a steel sphere corresponds to the theoretical times predicted by Newton's theory of gravity and measured by the SIRIUS sensor system and apparatus, an advanced system for measuring fall time. With around 20 to 25 students for each class, they were assigned in numerical order from A1 to A25. The students were encouraged to formulate hypotheses based on their previous understanding and theoretical readings about free fall. Some of the hypotheses presented were:

- A5: "I believe that bodies with greater mass reach the ground first due to the greater gravitational force acting on them."
- A16: "Objects, regardless of their mass, should fall with a time that is close to the time predicted by Newton's theory, according to the law of gravity, but I want to see it happen to believe it."

During the experiment, the students viewed the SIRIUS system and measured the falling time of the 33g sphere using simple stopwatches. The data collected was then compared with the theoretical times calculated based on the equations for uniformly accelerated movement under gravity without taking air resistance into account.

The discussions focused on the fact that the fall time of the sphere is reasonably equal to the theoretical free fall time and the time measured by the SIRIUS apparatus without taking air resistance into account, thus corroborating the theory of gravity which states that all objects in free fall under gravity must have the same acceleration.

Preliminary conclusions

- The students concluded that A16's hypothesis had been proven by the experiment, increasing their confidence in their theoretical understanding of physics and the accuracy of the SIRIUS system.
- The results demonstrated the effectiveness of laboratory practices in validating scientific theories through experimental methods and reinforced the students' understanding of the practical application of physics concepts.

- The experiment also effectively engaged the students, arousing their interest and motivation to explore physical phenomena further.

These activities highlighted the value of hands-on science education in the classroom, not only in terms of conceptual understanding but also in developing practical skills, critical thinking, and problem-solving.

Final Considerations

The Investigative Teaching Sequence strategy was well accepted by the students, as they were motivated and enthusiastic about carrying out the experiment and learning about the results. Some students didn't take part and one of the reasons may have been the number of students in the class, which exceeded what is recommended for a full laboratory, which is around 12 students. However, the students followed the steps of the scientific method, asked questions, collaborated with the explanations, and helped to average the results. The students took part in the activity with 80% participation. This strategy can be used for more active teaching and learning, awakening a taste for physics in high school students.

Vygotsky's approach to the Zone of Proximal Development (ZDP) is fundamental to understanding how to effectively apply investigative intervention in an educational setting (Vygotsky, 1986). By focusing on the differences between what students can do on their own and what they can achieve with help, this theory provides a solid basis for planning activities that expand their knowledge and skills (Vygotsky, 1984). In the Application of ZDP in Investigative Intervention, the role of the educator is crucial in mediating the learning process. Here are some ways in which Vygotsky's principles can be incorporated: Scaffolding, in this method the educator provides temporary structures to support students in carrying out tasks that they would not be able to do independently. This can include hints, reminders, examples, or adjustments to activities based on student responses.

In Guided Questioning, using strategically formulated questions, teachers can guide students through complex thought processes, challenging them to think critically and explore new ideas. In Modeling, demonstrating specific thought processes or tasks helps students visualize what is needed to achieve certain results. This is especially useful in science, where experimental processes and techniques can be complex. Peer Collaboration promotes group work and class discussions, students can learn from each other, each contributing their level of understanding and receiving insight from peers, which can push everyone beyond their initial individual capabilities, finally, Constructive

Feedback focuses on how improving and moving forward on specific tasks can help students understand their own mistakes and learn from them, providing opportunities to grow within their ZDP with benefits for learning.

By applying Vygotsky's principles in the investigative intervention, educators can promote greater conceptual understanding and students not only "learn the subject", but also develop a deeper understanding of how to apply knowledge in different contexts. It was a valuable experience and for greater results there would be a need for more contact with the students, making it possible to work on other concepts and with other equipment, making it possible to check their ability to make relationships.

Familiarizing them with the scientific method and the connections with everyday life was the main objective of these interventions. I believe that the difficulty in learning physics concepts and identifying them in everyday life may be related to a lack of interactivity with the students. The criteria that underpinned the methodology were fully met and it can be considered that this type of class provides students with a meaningful learning experience, stimulates scientific investigation, helps develop experimental skills, and consolidates the understanding of physics concepts, in this particular case, the concept of free fall.

Developing metacognitive skills with students so that they begin to learn to think about their thinking is crucial for autonomous and continuous learning. Increasing motivation and engagement to overcome challenges with the right support tends to get students more actively involved and they can feel more motivated to learn. This approach not only enriches the learning experience within the classroom but also prepares students for future challenges, reinforcing important skills for academic and professional life to come.

Thanks

The Federal University of Tocantins and the Frederico José Pedreira Neto State School.

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e-ISSN nº 2447-4266
Pslmss, v. 11, n. 1, 2025
http://dx.dxy.xrg/10.20873/hft.2447-4266.2021v11n1s05en

RESUMO
Este trabalho apresenta o relato sobre a metodologia empregada no sentido de melhorar o entendimento do conteúdo de física do Ensino Médio referente a Queda Livre. Por meio de experimentos de simples montagem e que possibilitaram realizar medidas da grandeza tempo de queda de uma esfera de aço foi possível fortalecer a compreensão do conceito em voga (queda livre). Foram distribuídos aleatoriamente cinco cronômetros entre os discentes, que registraram o tempo de queda da esfera repetindo 16 vezes a atividade. A abordagem, embora ainda inexpressiva frente as possibilidades que o aparato pode oferecer, foi relevante no sentido de despertar o interesse da maioria dos estudantes. Para comentar sobre o desenvolvimento cognitivo e habilidades de resolução de problemas, estimulação do pensamento analítico e a capacidade de enfrentar desafios mais complexos, exalta-se a necessidade de avançar na exploração do aparato e da teoria.

PALAVRAS-CHAVE: Queda Livre; Gravidade; Natureza.

RESUMEN
Este trabajo trae al público un informe de una metodología utilizada para mejorar significativamente la comprensión de los contenidos de Física de Secundaria en materia de Caída Libre, en clases que tuvieron como objetivo fortalecer la comprensión de los conceptos del contenido que pueden explicar los fenómenos naturales. A través de experimentos sencillos de montar, como medir el tiempo de caída de una esfera de acero mediante cronómetros, en este caso cinco cronómetros distribuidos aleatoriamente entre los alumnos. El análisis de los resultados y estas explicaciones permitieron mejorar las habilidades prácticas y experimentales, incluido el uso de equipos, la recolección de datos y el análisis de resultados. El enfoque contribuyó al desarrollo cognitivo y a las habilidades de resolución de problemas, estimulando el pensamiento analítico y la capacidad de afrontar desafíos más complejos. Además, la metodología, además de proporcionar familiarización con el método científico, contribuyó a familiarizar a los estudiantes con el método científico y su aplicabilidad en la vida cotidiana.

PALABRAS CLAVE: Caída libre; Gravedad; Naturaleza.