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ORIGINAL RESEARCH PAPER

Teaching electricity physics in high school using simple experimental projects

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ABSTRACT

The study of physics can be challenging for many students, particularly when access to practical resources that demonstrate physical laws is limited. Without the opportunity to observe scientific principles in their environment, students may struggle to comprehend these concepts, often resorting to rote memorization instead. In many Iranian schools, especially in rural areas, the scarcity or complete absence of laboratory equipment exacerbates this issue, hindering effective learning. This research aims to leverage the experiences of physics educators to propose easily accessible experiments that students can conduct, even at home, fostering a deeper understanding of physics principles. These proposed experiments are drawn from a global pool of innovative teaching practices, carefully summarized and adapted to the specific context and resources available within the country. It should be noted that the selection criteria for the projects and the steps taken to adapt them were there a consultation with teachers to select the most feasible ones. We encourage physics teachers to integrate these experiments into their curricula to enhance their students' comprehension, despite the constraints of limited laboratory facilities.

Keywords:
Physics Education,
At-home experiments,
Resource Limitations

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Introduction:

Experiments are essential tools in science education, playing a critical role in enhancing learning outcomes. The effectiveness and quality of learning resulting from practical work have been the focus of extensive research and discussion, underscoring its continued relevance in educational settings [1]. Engaging students in hands-on experimentation allows them to discover and apply scientific concepts actively, significantly enhancing their understanding and fostering motivation while satisfying specific curriculum requirements [1]. However, many students in primary and secondary schools, particularly those aspiring to careers in education under the auspices of the Ministry of Science or Education, face obstacles due to limitations in resources available for conducting physics experiments. This gap in available hands-on learning experiences is particularly pronounced in resource-limited settings, necessitating innovative approaches that can better engage students without requiring expensive equipment.

The importance of laboratory work as a crucial component of studying physics and other natural sciences cannot be overstated. It enables students to grasp practical concepts and skills while reinforcing theoretical knowledge [2]. Moreover, hands-on laboratory experiences can enhance students' curiosity and foster a positive attitude toward science [3]. Despite its significance, laboratory work often encounters challenges, including the high costs of equipment, limited access to materials, and potential risks associated with hazardous experiments [4]. Globally, reports highlight similar issues faced by students in various regions, particularly in developing countries where educational infrastructure may not support modern science education [5]. However, innovative integrations of information and communication technologies (ICTs)—such as simulations, animations, videos, and visualizations—into traditional laboratory work have shown promise in promoting effective learning [6]. One innovative approach is the integration of virtual laboratories with real practical laboratories, allowing for a blended learning experience [7].

While many existing studies highlight low-cost experiments, our project-based approach seeks to identify and create simple experimental setups that not only use readily available materials but also incorporate local contexts and cultural relevancy, further engaging students. Unlike traditional low-cost experiments common in literature, which may operate within predetermined frameworks, our designed experiments encourage creativity and independent problem-solving by allowing students to explore physics concepts using basic, resource-constrained materials that they can source locally. This approach aims to bridge the gap between theory and practice in physics education, particularly in environments with limited access to sophisticated laboratory equipment. A review of literature indicates that the use of contextually appropriate materials can significantly enhance student engagement and retention of scientific concepts [8, 9].

A virtual laboratory is defined as an online platform that offers a variety of experimental simulations and instructional videos, enabling students to conduct experiments in a virtual setting [10]. With access to laptops and smartphones, students can learn scientific concepts and acquire new skills using virtual labs anytime and anywhere [11]. These environments allow students to experiment with minimal negative consequences, enabling them to learn from mistakes and build confidence before engaging in real laboratory work. Furthermore, virtual laboratories facilitate experiments that might be challenging due to limited access to resources, high material costs, or safety concerns [12]. They empower students to visualize natural phenomena, collect data, formulate predictions, and develop hypotheses, actively involving them in the scientific research process [13].

The global perspective on educational technology illustrates a shift toward integrating digital resources to overcome barriers in resource-constrained environments. For instance, according to 2018 Global Education Statistics from Cambridge International University, Indonesian students are among the global leaders in benefiting from technology in education, with 67% using smartphones for learning and over 81% for homework [14]. Likewise, the COVID-19 pandemic has accelerated the adoption of online learning, allowing educators worldwide to recognize the advantages of technology in education and its potential for enhancing learning outcomes [15]. However, despite these advances, many teachers worldwide report challenges in conducting physics experiments due to insufficient laboratory equipment, limited access to smartphones and laptops in schools, and lack of training in using these tools effectively [16, 17].
According to Ateş and Eryılmaz, numerous scientific experiments can be carried out using simple setups and low-cost materials that are readily available and easy to assemble [18]. The evolution of science curricula has been significantly enriched by learning through simple tools and manual methods, particularly during the early 1960s and 1970s [19]. These accessible learning activities are especially vital for developing countries that may lack the resources to procure expensive materials, enabling students to engage actively in their scientific education. Evidence from multiple studies suggests that experiential learning through simple and contextually relevant projects can enhance conceptual understanding and increase student motivation [20, 21].

Building on these experimental findings, our planned approach focuses on the 11th-grade experimental physics textbook used in Iran, with the goal of simplifying its content and designing experiments that allow students to conduct physics experiments outside the traditional school environment. By creating a series of accessible, project-based experiments that require minimal resources, we aim to deepen students' understanding of physics topics, promote experiential learning, and directly address the resource constraints that often hinder practical science education. Ultimately, our approach aspires to contribute to a more inclusive model of science education that recognizes and bridges the gaps in educational resources across diverse global contexts.

Methodology

This research endeavors to develop practical projects by reviewing various sources and experiments carried out by teachers in different countries. The objective is to adapt and re-evaluate these projects in the context of available resources and conditions in Iran. Ultimately, the study aims to present a selection of practical projects tailored to enhance educational experiences in the region.

Findings

In this research, five projects were thoroughly reviewed and subsequently introduced:

1- Project One: Constructing an Electroscope Using Simple Tools

Objectives of the First Project:
- Understand the structure and components of a simple electroscope.
- Detect the presence or absence of electrical charge in an object using the electroscope.
- Design and implement new experiments to create different variations of electroscopes.

Experiments Overview

An electroscope is a scientific instrument used to detect the presence of electric charge on an object. The first electroscope, known as a vesorium, was an axial needle electroscope invented in 1600 by the British physicist William Gilbert. In this project, students will construct an electroscope using simple tools and subsequently investigate the presence or absence of electric charge in various objects. The project will culminate in the preparation of a comprehensive report that details their understanding of the underlying concepts and presents their experimental results.

Group Size:

3 to 5 students per group.

Duration:

Approximately 2 hours.

Necessary Materials for the First Project:

- Copper wire
- Pliers
- Plastic (or glass) container with a lid
- Plastic straw
- Aluminum foil
- Electric glue
- Balloons

Activity Steps:

1. Cut a section of copper wire for the electroscope, adjusting the length based on the container size. Bend the wire into an L-shape.
2. Using pliers, twist one end of the wire into a flat spiral, which will serve as the part of the electroscope that collects electric charge from other objects.
3. Prepare a plastic or glass container with a lid, and drill a hole in the center of the lid. Ensure the hole is wide enough to accommodate a plastic straw.
4. Cut a piece of straw and insert it through the hole in the lid. Secure it in place with hot glue at both the top and bottom to prevent movement.
5. Pass the wire prepared in step 2 through the straw, positioning the straight section at the bottom and the spiral section at the top.
6. Bend the straight end of the wire into a U shape (wire hook) using your fingers or needle-nose pliers. This hook will be positioned inside the container.
7. Cut two identical pieces of aluminum foil, ensuring they are the same size and shape.
8. Pierce the narrow end of each piece of foil and slide them onto the wire hook, ensuring the two foil pieces are in contact; otherwise, the electroscope will not function properly.
9. Place the lid on the container, ensuring the aluminum foil reaches about halfway down. Secure the lid to the container with electrical tape.
10. Your electroscope is now ready for use (Figure 1)! Keep it in a cool, dry environment, as humidity can affect its performance. For a visual reference, you can view the design of a handmade electroscope at [this link](https://www.youtube.com/watch?v=wso0FqcnG7g&t=1m59s).

To test the electroscope, charge a balloon by rubbing it and bring it close to the end of the copper wire. Observe and record the reactions of the aluminum foil strips.

Student Feedback

After completing the experiments, the students will collaboratively write a report structured as follows:

- Introduction: Outline the application of the electroscope, the project's objectives, and the expected learning outcomes.

- Development: Provide a brief history of the electroscope and describe its applications. Explain the experiments conducted, the observations made, and the methodology used. Present and discuss the results.
- Conclusion: Reassess the project's objectives, reflect on what was learned, and draw conclusions based on the experiments and observations.
- References: Include citations for all sources used, such as books, articles, and webpages relevant to the research and project.

Teacher Insights

This project equips students with the practical knowledge of building and using an electroscope and fosters teamwork and collaboration. Each group member is encouraged to contribute to all sections of the report, with all names included on the cover page. The report should be between 5 to 10 pages, clearly written, comprehensive, and organized, utilizing scientific and formal language.

Through this engaging project, students will enhance their understanding of how to construct and operate an electroscope using simple tools at home, allowing them to detect the presence or absence of charge in various objects. Additionally, they will learn the importance of collaboration and effective communication, which are essential skills in both academic and professional settings.

Figure 1. Schematic of a homemade electroscope.

2. The Second Project: Understanding Electric Charge Distribution and the Principle of Charge Conservation

Objectives of the Second Project:

- Comprehend the principles of charge distribution and conservation.
- Learn to systematically conduct and analyze experiments.
- Develop skills in teamwork, communication, problem-solving, and creative thinking.

Experiments Overview

In this project, students will explore various methods of charge distribution and verify the principle of charge conservation through simple and engaging experiments. The project will culminate in a comprehensive report highlighting the concepts learned and the results of the experiments.

Group Size:

3 to 5 students per group

Duration:

Approximately 2 to 3 hours

Required Materials for the Second Project:

- Balloons
- Wool or fur fabric
- Pieces of aluminum foil

- Electroscope (homemade or purchased)
- Insulated copper wire
- Battery (1.5 V)
- Lamp (compatible with battery voltage)
- Paper, pencil, and ruler for drawing diagrams

Steps for Conducting the Activity:

1. Understanding Charge Distribution:
   - Inflate a balloon, tie it off, and rub it with a piece of wool or fur. This action imparts a net charge to the balloon through friction.
   - Bring the charged balloon close to the pieces of aluminum foil and observe the reaction. Record your observations.
   - Repeat the experiment using different materials and discuss your findings. This demonstrates how charges distribute themselves in response to a charged object.
2. Conservation of Charge:
   - Construct a simple circuit using insulated copper wire, a battery, and a light bulb. Note that the bulb lights up when the circuit is complete, indicating current flow (the movement of charge).
   - Break the circuit at any point and observe that the bulb turns off, signifying the cessation of current flow. This experiment illustrates the principle of charge conservation: the total charge in a closed system remains constant.

Student Feedback

After completing the experiments, students will collaboratively write a report organized as follows:

- Introduction:
  Describe the relevance of charge distribution and conservation in physics and the real world, outline the purpose of the project, and specify the expected learning outcomes.
- Development:
  Explain the theoretical background of charge distribution and conservation. Describe the experiments conducted, the observations made, and the methods used. Present and discuss the results in relation to the theoretical concepts learned.
- Conclusion:
  Revisit the project’s objectives, summarize key learnings, and draw conclusions based on experimental observations.
- References:
  List all sources consulted during the research and project work, including books, webpages, and videos.

This project not only deepens students' understanding of charge distribution and conservation but also promotes teamwork and collaboration. Each group member is expected to contribute to all sections of the report, with all names included on the cover page. The report should be 5 to 10 pages long, clearly written, comprehensive, and organized, employing scientific and formal language.

Teacher Insights

Through this engaging project, students will gain a practical understanding of charge distribution and conservation concepts. Additionally, they will learn the value of collaboration and communication—skills that are essential in both academic and professional settings.

3- Project Three: Building a Van de Graaff Generator with Simple Tools

Objectives of the Third Project:

- Understand the structure and functioning of a Van de Graaff generator.

- Enable students to construct a Van de Graaff generator using readily available materials and understand its operation.
- Describe the various applications and uses of this generator in detail.

Experiments Overview

The Van de Graaff generator is a device designed to generate static electricity for various experiments. It was invented in 1931 by American physicist Robert Jamison Van de Graaff. This device can produce extremely high voltages—up to 20 million volts—originally intended to provide the energy needed for early particle accelerators. These accelerators, often referred to as "atom smashers," accelerate subatomic particles to incredibly high speeds, allowing them to collide with target atoms. Such collisions can generate new subatomic particles and high-energy radiation, such as X-rays. The capabilities of the Van de Graaff generator form the basis of many concepts in particle and nuclear physics.

There are two main types of Van de Graaff generators: one utilizes a high-voltage power supply, while the other employs belts and rollers to charge objects. In this project, students will conduct an experiment to build a Van de Graaff generator using simple materials. The outcomes will be documented in a comprehensive report.

Group Size:

3 to 5 students per group

Duration:

Approximately 2 to 3 hours

Necessary Materials:

- Support base
- DC motor
- Three-way pipe
- Connecting pipe
- Straight pipe
- Cardboard
- Belt
- Battery
- Electric glue
- Glass tube
- Nail
- Metal can
- Connecting wires

Note: All pipes used in this project should be made of polyvinyl chloride (PVC).

Steps for Conducting the Activity:

1. Prepare the Motor:
   - Wrap electrical tape around the shaft of the DC motor, then attach a glass tube to the shaft (Figure 2. a).

2. Setup the Motor:
   - Place the motor inside the tee pipe. Attach one end of the belt to the motor shaft, ensuring it is snug. Insert an electric wire from the outside of the pipe so that it is close to the belt (Figures 2. b and 2.c).

3. Assemble the Pipes:
   - Connect the three-way pipe, connecting pipe, and straight pipe, simultaneously feeding the other end of the belt through all three pipes so the belt emerges from the straight pipe. Create two holes at each end of the straight pipe, inserting a nail through

one end. Pass the nail through the glass tube and the belt as illustrated, and pull the other end of the nail through the hole in the tube (Figure 2.d).

4. Secure the Assembly:
   - Fasten the entire assembly to the support base to ensure stability during operation.
5. Connect the Power Supply:
   - Drill a hole on the opposite side of the straight pipe and pass one end of the power wire through this hole near the top of the belt.
6. Install the Cardboard:
   - Place a cardboard circle, cut to fit the diameter of the straight pipe, through the pipe. Direct the other end of the electric wire into the metal can, and secure the can in place over the assembly (Figure 2.e).

7. Power the Generator:
   - Use the free end of the lower wire as a ground connection, then connect the two terminals of the DC motor to the battery. As the motor drives the belt, static charge will begin accumulating in the metal can (Figure 2.f).

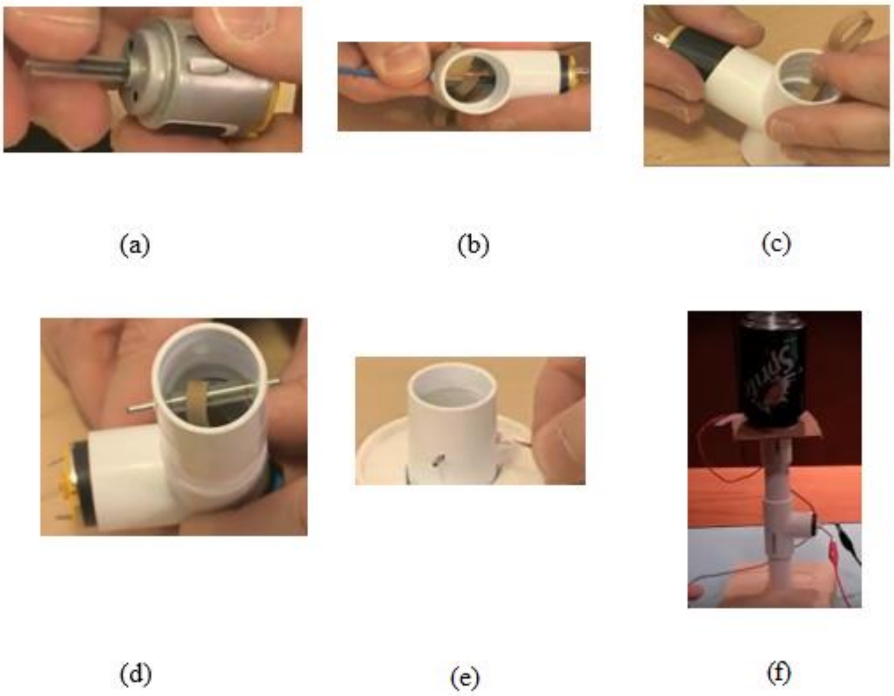

Figure 2: Sequential Steps for Assembling a Homemade Van de Graaff Generator

After completing these steps, if you touch the metal can, you will feel a spark generated due to the accumulated charge. Similarly, bringing a neon lamp close to the can will cause it to glow. You can test the lamp's brightness at various distances from the generator; the closer the lamp is, the brighter it will shine. Figure 3 illustrates the repulsion effect between electric charges on aluminum foil when the Van de Graaff generator is operating.

Figure 3: The effect of charge repulsion on aluminum foils in the Van de Graaff generator.

Student Feedback

Each student group should write a report after completing the experiments, structured as follows:

- Introduction:

Explain the operational principles of the Van de Graaff generator, the project's purpose, and the anticipated learning outcomes.

- Development:

Describe the generator's structure and applications. Detail the experiments conducted, observations made, and methods used. Discuss the interactions between different charged objects and present the results, interpreting them based on theoretical knowledge.

- Conclusion:

Re-evaluate the project's objectives, summarize what was learned throughout the process, and draw conclusions based on experimental findings.

- References:

Cite all sources consulted during the research and project preparation, including books, websites, and videos.

Teacher Insights

This project not only enhances students' understanding of the Van de Graaff generator's structure and applications but also encourages teamwork and collaboration. Every team member is expected to contribute to all sections of the report, and all names should be included on the cover page. The report should span 5 to 10 pages, be clearly articulated, comprehensive, and well-organized, utilizing formal scientific language.

Through this hands-on project, students will deepen their understanding of the Van de Graaff generator while developing essential skills in collaboration and communication—attributes that are invaluable in both academic and professional contexts.

4. Project Four: Demonstrating the Electric Field

Experiments Overview

An electric field is an intrinsic electrical property present at any point in space where an electric charge exists. The strength and direction of an electric field are represented by the symbol E, known as the electric field strength, intensity, or simply the electric field. Visualizing electric fields can be effectively achieved through electric field lines, a concept first introduced by Michael Faraday. The density of these field lines around a point reflects the relative strength (magnitude) of the electric field in that area. Specifically, when the density of electric field lines is higher near point A compared to point B, it indicates that the electric field at point A is stronger.

Key characteristics of electric field lines include:

- They never intersect.

- They are always perpendicular to the surface of the charged object.
- The number of field lines emanating from a charge is proportional to the magnitude of the charge itself.
- Electric field lines originate from positive charges and terminate at negative charges.
- These lines can be considered to extend to infinity, showing that they do not have defined starting or ending points.

Next, students will conduct a straightforward experiment that will make electric field lines easily observable.

Group Size:

3 to 5 students per group

Duration:

Approximately 1 to 2 hours

Necessary Materials:

- Van de Graaff generator
- Connecting wires
- Electric wire plug with multiple strands (to indicate points of the electric field)
- Twisted brass wire shaped into a ring with threads attached (to represent the electric field around a ring)
- Two conductive plates facing each other, with threads attached to one plate (to demonstrate a uniform electric field)

Procedure for Conducting the Experiment:

1. Setup the Threaded Plug:
   - Begin by placing the threaded plug onto the Van de Graaff generator. At this stage, ensure that the threads are untangled and do not exhibit any specific shape.
   - Turn on the Van de Graaff generator. Once activated, allow the threads to arrange themselves according to the electric field, as illustrated in the accompanying figure. This arrangement demonstrates the electric field lines present at the designated point.
2. Electric Field Around a Metal Ring:
   - Gradually bring the metal ring closer to the Van de Graaff generator. As you do this, observe that the threads will align with the electric field direction (as shown in the figure).
   - It is noteworthy to mention that when the generator is on, there are no threads within the loop of the ring. This observation confirms that the electric field inside a conductor is zero, illustrating the electric field configuration around a ring conductor.
3. Visualizing the Electric Field Between Parallel Plates:
   - Next, examine the electric field between two parallel conductive plates. Connect one end of a connecting wire to the Van de Graaff generator and attach it to one of the plates.
   - Connect the other ends of the connecting wire to the ground terminal of the Van de Graaff generator and the plate that has threads attached. Upon activation of the generator, one of the plates will acquire a positive charge while the other will attain a negative charge.
   - Inspect the threads situated between the two plates; they should appear approximately parallel. This parallel configuration indicates that the electric field between the two conductive plates is uniform.

Student Feedback

After completing the experiments, each student group is required to compose a report structured as follows:

- Introduction:

Explain the concepts of electric fields and electric field lines, outline the project's purpose, and detail the expected learning outcomes.

- Development:
  Describe the theoretical concept of electric fields and the methods used to visualize the electric field around charged objects. Explain the experiments conducted, the observations recorded, and the techniques employed. Present and discuss the experimental results in detail.
- Conclusion:
  Reiterate the project's objectives, summarize key learnings derived from the project, and draw conclusions based on the experiments and observations made.
- References:
  List all sources consulted during the project development, including textbooks, articles, and online resources.

Teacher Insights

This project not only enhances students' comprehension of electric field concepts but also aids in visualizing electric field lines and their intensity in the vicinity of charged objects. It fosters teamwork and cooperation as each team member actively contributes to the report, which should include all participants' names on the cover page. The report should be between 5 to 10 pages, demonstrating clarity, completeness, and organization, and should be written in a formal scientific style.

Through this engaging and hands-on project, students will solidify their understanding of electric field lines while also appreciating the significance of collaboration and effective communication—skills that are invaluable in both academic and professional settings.

5. Project Five: Understanding Lenz's Law Through a Simple Experimental Design

Objectives of Project Five:

- To facilitate a clear understanding of Lenz's law.
- To enable recognition of Lenz's law applications in everyday surroundings.
- To empower students to design alternative experiments that demonstrate Lenz's law.

Experiments Overview

A well-known demonstration of magnetic braking and the principles of Lenz's law involves a cylindrical magnet falling through a copper or aluminum tube. However, this demonstration typically requires schools to purchase cylindrical neodymium iron boron (NdFeB) magnets, which can be costly. Additionally, students are unable to observe the magnet's movement clearly within the tube. Research articles note alternative methods for conducting this experiment [22, 23]. In this project, students will learn a simple and cost-effective approach to visualize magnetic braking and Lenz's law while circumventing the aforementioned issues.

Group Size:

3 to 5 students per group

Duration:

Approximately 1 to 2 hours

Necessary Materials:

- Simple toy car

- Neodymium iron boron (NdFeB) magnet (sourced from a broken computer hard disk)

- Plate made of dielectric material (wood or plastic)

- Plate made of non-magnetic metal (aluminum or copper)

- Elastic band

The NdFeB magnet, known for producing a strong magnetic field, is particularly effective for demonstrations of electromagnetism [24] and electromagnetic induction [25].

Procedure for Conducting the Experiment:

1. Prepare the Car and Magnet:

   - Attach the NdFeB magnet securely to the bottom of the toy car using an elastic band.

2. Set Up the Inclined Plane:

   - Position the wooden plate to create a sloped surface.

3. Conduct the First Test:

   - Release the car from the top of the slope. As students are already aware, mechanical laws dictate that the speed of the car will increase as it descends.

4. Set Up the Aluminum Plate:

   - Now place the aluminum plate in a manner that it forms a slope similar to that of the wooden ramp. Position the car at the top of this incline and let it go. Students will be surprised to observe that the car comes to a stop, demonstrating the braking effect [26] (Figure 4).

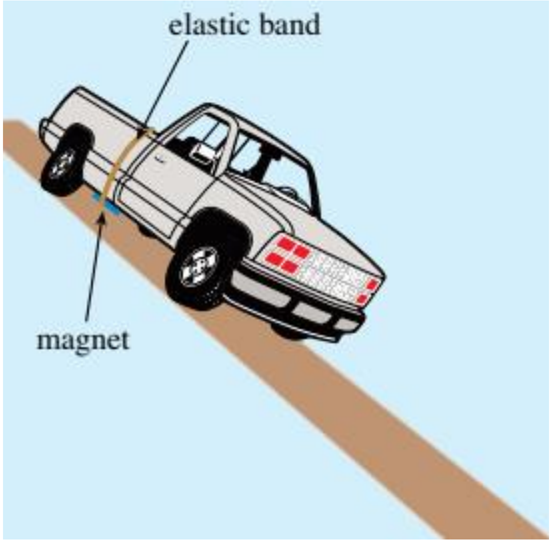

Figure 4. Schematic of the car and inclined plane [26].

Explanation of Observations:

The interaction between the moving magnet and the metal plate induces an electric current in the metal, as described by Faraday's law of electromagnetic induction. According to Lenz's law, this induced current generates a magnetic field that opposes the original magnetic field of the descending magnet. Consequently, the car experiences braking due to this magnetic repulsion. In contrast, since wood and plastic do not conduct electricity, the car continues to accelerate on those surfaces.

Experimental Variations:

Several modifications can be explored in this experiment:

- Utilize plates made from different metals of equal thickness.

- Use plates made from the same metal but of varying thicknesses.

- Adjust the distance between the magnet and the metal plate.

In all cases, it is beneficial to quantitatively measure changes in velocity using sensors, as these values are directly related to the intensity of the induced currents in the metal.

Student Feedback

After completing the experiments, each student group is required to write a report structured as follows:

- Introduction: Discuss the concept of magnetic braking, outline the project’s purpose, and specify the expected learning outcomes.

- Development: Explain the concept of magnetic braking and its relevance to daily life. Detail the experiments conducted, the observations made, and the methodologies employed. Present and analyze the results in depth.

- Conclusion: Revisit the project’s objectives, summarize the learning gained through the project, and draw conclusions based on the experimental findings and observations.

- References: Provide a list of all sources consulted during the project development.

Teacher Insights

This project not only enhances students' understanding of magnetic braking but also fosters recognition of its applications in real-world contexts. Moreover, it encourages teamwork and collaboration, with each group member contributing to all sections of the report, which should include the names of all participants on the cover page. Each report should be between 5 to 10 pages, demonstrating clarity, completeness, and organization, and should be written in a scientific and formal tone. Through this engaging and hands-on project, students can deepen their grasp of the challenging concept of magnetic braking, while also appreciating the importance of collaboration and effective communication—essential skills in both academic and professional settings.

Conclusion

In conclusion, laboratories play a crucial role in teaching scientific disciplines, enabling students to engage in hands-on experiences through experiments and fostering an atmosphere of collaboration and participation. Recently, there has been a growing interest in the implementation of remotely accessible laboratories as an alternative solution. These remote labs utilize high-speed networks, allowing students and educators to perform experiments on real laboratory equipment from a distance. They offer significant advantages, such as resource sharing among schools worldwide and access to facilities that might otherwise be too costly or technically unfeasible.

However, many low-income schools in Iran still face challenges in accessing computers and high-speed internet, limiting the potential of remote laboratories. To address these issues, this article proposes a series of experiments that utilize readily accessible materials, enabling students to explore the laws of physics independently, even at home. The proposed experiments are designed around five primary projects, each aimed at engaging students in practical, hands-on learning experiences that promote both understanding and enthusiasm for physics. By simplifying complex concepts and employing materials that are easily obtainable, these experiments can significantly contribute to lowering barriers to scientific education in resource-limited contexts. The broader impact of these findings extends beyond the immediate learning outcomes for students. By fostering an environment in which students can independently explore scientific concepts, these experiments are likely to contribute to long-term improvements in science education in resource-limited areas. Enabling students to conduct experiments with minimal resources encourages a culture of inquiry, critical thinking, and problem-solving skills that are essential for future scientific endeavors. Furthermore, successful implementation of these projects may serve as a model for other subjects, demonstrating that similar hands-on learning opportunities can be created using low-cost, locally available materials. This approach not only helps to democratize education but also takes into consideration the specific cultural and socio-economic contexts of diverse regions.

The implications of these findings extend beyond physics and could influence the teaching of other scientific disciplines, including chemistry and biology, as well as subjects such as mathematics and engineering. The emphasis on experiential learning through accessible materials can inspire the development of similar projects in a variety of educational contexts, enabling students across different disciplines to engage in meaningful, practical applications of their studies. Future research directions should focus on scaling these experiments across different schools, testing their effectiveness with larger student populations, and gathering data on student engagement and learning outcomes. Collaborating with educators in various regions can facilitate the adaptation of these experiments to align with local curricula and resources. Additionally, investigating the integration of low-cost digital tools—such as mobile apps or online platforms for data collection and analysis—could create blended learning experiences that further enhance student learning. By leveraging technology in a thoughtful manner, educators can reach a broader audience and provide students with the necessary skills to navigate the increasingly digital landscape of modern science and technology. Ultimately, the proposed experiments not only aim to enrich students' understanding of physics but also seek to empower them to take ownership of their learning experiences. As students engage with scientific concepts through these accessible projects, they build a foundation of knowledge and skills that can lead to increased interest in STEM fields, greater scientific literacy, and a more informed and innovative future generation.

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