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Design and Development of a Physics Laboratory Tool Based on Arduino Nano Sensor for the Topic of Uniformly Accelerated Linear Motion (UALM)

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ABSTRACT

Instructional aids serve as tools used in the teaching process to provide a clearer understanding of concepts and learning materials. The aim of this research is to design, assess the feasibility, and test the accuracy of a physics instructional aid based on Arduino Nano sensor for the topic of Uniformly Accelerated Linear Motion (UALM). The methods used in this research are literature review and design and development. This research consists of two stages: the first stage is the design stage of the instructional aid, and the second stage is the feasibility test of the instructional aid. In the design stage, there are five steps involved: preparing the tools and materials, assembling the track board, assembling the Arduino Nano and distance sensor circuit, assembling the components of the practical apparatus, and evaluation. The feasibility test of the Arduino Nano instructional aid was conducted through two experiments. From the results of the first experiment, testing the feasibility of the Arduino Nano instructional aid for Uniformly Accelerated Linear Motion (UALM), two findings were obtained. In the first experiment, when the time and angle varied, the graph showed that time is inversely proportional to the angle. On the other hand, in the second experiment, when the time and distance varied, the graph indicated that time is directly proportional to the distance

INTRODUCTION

Physics is a discipline that serves to explain natural phenomena. It is one of the branches of natural sciences that, in its research, is not only concerned with formulas but also with concepts, principles, and research discoveries related to the occurrences and interactions that take place in nature (Yudiafarani et al., 2022). Physics education is a part of the branch of science. In the implementation of physics education, a thorough understanding of physics concepts is necessary so that students can solve physics problems easily and quickly (Hidayatin et al., 2022). However, in the process of physics learning in the classroom, there are several obstacles that are encountered, such as a lack of student motivation and interest, which results in low scores on daily assessments. One of the causes is the students' lack of mathematical abilities, making it difficult for them to solve physics problems. Furthermore, the majority of physics concepts taught in high school are abstract in nature, making it difficult for students to grasp these concepts without concrete evidence. This often leads students to feel bored during the learning process (Tina et al., 2021).

Physics is also a branch of experimental science or science that is built upon a series of experiments. Through these experiments, laws and statements discussing the concepts of physics are obtained. These concepts and laws are learned through laboratory experiments conducted in the laboratory (Maiyena et al., 2018). One way to enhance scientific or experimental process skills is by utilizing the method of laboratory experiments. Through laboratory experiments, students can develop process skills as well as psychomotor, cognitive, and affective skills. The development of science process skills can also be achieved through experiential-based learning, commonly known as laboratory experiments (Putri et al., 2022).

The success of conducting physics laboratory experiments is greatly influenced by the availability of adequate instructional aids. Instructional aids serve as tools used in the teaching process to provide a clearer understanding of concepts and learning materials. The use of instructional aids can enhance motivation and encourage learners to be more active, thus creating an interactive and non-monotonous learning environment. (Masyruhan et al., 2020). Furthermore, the use of instructional aids can develop critical thinking skills in learners and help them become more actively engaged in the learning process. However, based on the observation of physics laboratory practices in high schools, some of the equipment used is still analog and manual. This results in relatively low accuracy in the obtained results, making it difficult for students to validate the concepts they have learned, such as in the case of Uniformly Accelerated Linear Motion (UALM) experiments. Therefore, there is a need for appropriate practical apparatus that are easy to understand and capture students' attention (Sebastian et al., 2021).

This research designs a digital-based practical apparatus for Uniformly Accelerated Linear Motion (UALM) using Arduino Nano as its main component. Arduino is a single-board microcontroller, an open-source platform that originated from the wiring platform and is designed to facilitate electronic usage in various hardware fields. It features the Atmel AVR processor and has its own software program (Santoso and Wijayanto, 2022). Arduino has the ability to detect its surrounding environment through various available sensors and can control lights, motors, and various other types of actuators. In the development of practical tools, Arduino Uno is chosen due to its advantages compared to other microcontroller boards. In addition to its open-source nature, Arduino also has its own programming language, which is based on the C language. Furthermore, the Arduino board is equipped with a USB loader, facilitating the programming process of the microcontroller within Arduino (Tina et al., 2021). Microcontroller technology that utilizes a computer as its brain can be utilized in the creation of practical tools, such as in the case of linear motion experiments. In this case, the Arduino microcontroller serves as the main system that controls and processes the entire apparatus. This technology enables the microcontroller's output to be highly precise, resulting in more accurate data. (Candra Yusro et al., 2019).

Therefore, this research aims to design, assess the feasibility, and test the accuracy of a physics instructional aid based on the Arduino Nano sensor for the topic of Uniformly Accelerated Linear Motion (UALM).

LITERATURE REVIEW

Instructional Aids

One of the effective teaching methods in explaining abstract concepts and generating students' interest in learning is the use of instructional aids or practical experiments. Instructional aids serve as learning media that reflect and illustrate the concepts being taught. In the learning process, instructional aids can help clarify the messages and information conveyed by the teacher regarding physics lessons. The use of instructional aids assists students in understanding abstract concepts and making them more tangible. According to the cone of experience concept by Dale, learning through real actions clarifies a concept and helps students remember what has been done. Therefore, learning becomes more easily understood when suitable instructional media are used. Instructional aids play a role as a means of communication and interaction between teachers and students in the learning process. Instructional aids serve as a medium to convey messages, thereby stimulating students' thoughts, emotions, attention, and learning interests. The use of instructional aids in learning creates a series of activities aimed at providing students with opportunities for active learning. By utilizing instructional aids, students can acquire knowledge, develop motor skills, and stimulate their creativity in problem-solving. Consequently, it fosters a high-quality learning process(Kause, 2019).

Arduino Nano

Arduino Nano is a development board composed of a microcontroller based on the Atmega 328P chip and has a very compact form. The Arduino Nano features 14 digital pins, which can function as input or output pins. Among these, 6 pins are dedicated to PWM output, and there are 6 analog input pins as well. It also includes a 16MHz crystal oscillator, USB connectivity, and a reset button. However, the Arduino Nano does not have a DC power jack. Furthermore, the Atmega 328P has a hardware component with an Atmel AVR processor. The programming language used in Arduino Nano is the C language (Supriyatna *et al*., 2021).

Uniformly Accelerated Linear Motion (UALM)

Kinematics is a fundamental science that serves as a basis before researching dynamics. This is because in the dynamics topic, a more in-depth discussion will be conducted. Therefore, it is necessary for us to research kinematics in order to facilitate our understanding of dynamics. In kinematics, we delve into Uniform Linear Motion and Uniformly Accelerated Linear Motion. (Handayani *et al*., 2019). However, this time we will only discuss Uniformly Accelerated Linear Motion. However, this time we will discuss Uniformly Accelerated Linear Motion (UALM) only. UALM is a motion in which the trajectory is a straight line and the velocity changes regularly with constant or uniform acceleration. In UALM, there are generally three variables: velocity, acceleration, and displacement. UALM has a positive value when experiencing acceleration and a negative value when experiencing deceleration (Nurullaeli, 2020).

METHOD

The method used in this research consists of literature review and design and development based on existing references. The initial design was created following the reference materials, and further development was conducted. After completing these steps, the software and hardware requirements for constructing the physics practical apparatus for uniformly accelerated linear motion based on Arduino Nano were analyzed.

This research consists of two phases. The first phase is the design phase of the teaching aid, followed by the second phase, which is the feasibility testing phase. The design phase of the teaching aid involves five steps: equipment and material preparation, assembly of the track board, assembly of the Arduino Nano circuit and distance sensor, assembly of the practical apparatus components, and finally, evaluation.

After going through a series of processes to produce a teaching aid as initially planned, the next step is to conduct feasibility testing or validation of the teaching aid. The purpose of this feasibility testing is to analyze the results and determine the compatibility of the teaching aid with the initial plan for its development (Masyruhan et al., 2020). In this practicality test of the laboratory apparatus, experiments on Uniformly Accelerated Motion (UALM) are conducted using the designed laboratory apparatus. Subsequently, the results of the practicality test are compared with the calculations based on existing literature formulas. If the results obtained from the feasibility test align with the existing literature, the laboratory equipment can be considered final. However, if the feasibility test results do not match the existing literature, improvements need to be made to the laboratory equipment until it yields results that align with the literature (Aprillia et al., 2022).

RESULT AND DISCUSSION

Laboratory Equipment Design Process

The process of designing this laboratory equipment begins with the design stage. The design of this laboratory equipment consists of an inclined plane track board with a length of 100 cm and the Arduino Nano circuit along with the distance sensor. The production of this laboratory equipment involves five stages: preparing the tools and materials, assembling the track board, assembling the Arduino Nano circuit and distance sensor, assembling the components of the laboratory equipment, and the final stage, which is evaluation. These five stages can be explained as follows:

Stage 1: Preparing the Tools and Materials

The tools used in the production of this laboratory equipment include a soldering iron, scissors, saw, and screwdriver. Meanwhile, the materials used in the production of this laboratory equipment include wooden board, bow, measuring tape, IR obstacle sensor, 16x2 LCD screen, black box (X4), door hinge, reset button, Arduino Nano ATM328p microcontroller module, I2C module, breadboard, spiral cable, jumper cables, mini USB cable, phone charger adapter, toy car, adhesive tape, screws, nuts, nails, and selfie stick.

Stage 2: Assembling the Track Board

The track board is assembled using wood materials. This track board is designed as an inclined plane used for toy car racing. The dimensions of the inclined plane on the track board are 100 cm in length with a track width of 5 cm. At the bottom of the track board, there is a horizontal wooden base serving as the foundation. Between the track board and the horizontal board, there is a hinged door that allows for adjustable angles of inclination on the track board. The angles of inclination can be adjusted by using support wood that can be positioned and secured with screws and nuts.

Figure 1. Track Board

Stage 3: Assembling the Arduino Nano Circuit and Distance Sensor

The Arduino Nano ATM328p circuit and distance sensor are used as the time measurement module. The steps for connecting the Arduino Nano and the distance sensor are as follows: (1) The LCD screen is connected to the I2C module. (2) The Arduino Nano is connected to the breadboard, and then the LCD screen and IR obstacle sensor are connected to the breadboard using jumper wires. (3) Installing the Arduino Uno software. (4) Connecting the Arduino circuit to a laptop for coding purposes. (5) After completing the coding process, the Arduino Nano circuit is placed inside a box (Kadir, 2015).

After assembling the Arduino Nano and the distance sensor, the Arduino circuit is ready to be used for measuring time based on the two distance sensors. If an object passes through the first sensor and reaches the second sensor, the time taken by the object to pass through the two sensors will be displayed on the LCD screen. The time displayed on the LCD screen can be used to measure the magnitude of the acceleration experienced by the object during its motion (Dinata, 2015).

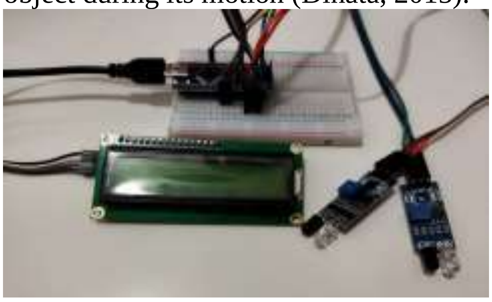

Figure 2. Arduino Nano Connected to the Breadboard, LCD Screen, and IR Obstacle Sensor

Stage 4: Assembling the Components of the Laboratory Equipment

The fourth process in the production of this laboratory equipment is the assembly of its components. This process can be carried out once the track board and Arduino circuit have been assembled. The fourth process involves combining the track board with the Arduino circuit. The track board has been prepared beforehand with a designated space at the bottom of the track board for placing the LCD screen and Arduino circuit. The Arduino Nano circuit board is first placed inside the box along with the LCD screen. Next, the IR Obstacle sensor is installed. The first sensor is positioned on the top part of the track board. To facilitate adjustment according to the independent variable, which is distance, the first sensor is mounted using a selfie stick.

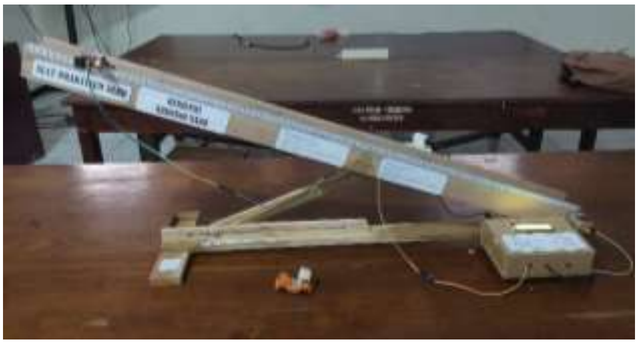

Figure 3. Final Product

Stage 5: Evaluation

The final stage in the design of the laboratory equipment is the evaluation stage. After the assembly process of the laboratory equipment is completed, a test will be conducted to assess its performance. The test will involve two types of experiments. In the first experiment, the following variables will be used: the independent variable is the angle of inclination, the dependent variable is time, and the controlled variables are distance and gravitational acceleration. Then, in the second experiment, the following variables will be used: the independent variable is distance, the dependent variable is time, and the controlled variables are the angle of inclination and gravitational acceleration. This laboratory equipment is designed to measure the time required for an object to traverse an inclined plane according to the predetermined distance. In order to determine the acceleration experienced by the object, manual acceleration calculations using the equation of Uniformly Accelerated Linear Motion (UALM) must be performed. The formula used is as follows:

$$t = \sqrt{\frac{2s}{g\ sin\theta}}$$

Feasibility Test

The feasibility test of the laboratory equipment was conducted through laboratory testing. The laboratory testing involved performing an experiment on Uniformly Accelerated Linear Motion (UALM) using the assembled laboratory equipment, and then comparing the results obtained from the equipment with the calculated results from the formula. Table 1 presents the results of the first experiment, while Figure 11 illustrates the graph of the first experiment results.

Table 1. Results of the First Experiment

Number	Distance (m)	Theta θ	sin θ	Gravitation (m/s^2)	Times (s) (measurement)	Times(s) (calculation)
1.	0,9	15°	0,258	10	0,813	0,835
2.	0,9	20°	0,342	10	0,710	0,725
3.	0,9	25°	0,422	10	0,623	0,653
4.	0,9	30°	0,500	10	0,593	0,600
5.	0,9	35°	0,573	10	0,530	0,560

According to Table 1, it is evident that time is inversely proportional to angle. As the angle increases, the acceleration also increases, resulting in less time required.

Table 2. Results of the Second Experiment.

Number	Distance (m)	Theta θ	sin θ	Gravitation (m/s2)	Times (s) (measurement)	Times(s) (calculation)
1.	0,5	15	0,258	10	0,599	0,622
2.	0,6	15	0,258	10	0,653	0,681

3.	0,7	15	0,258	10	0,728	0,736
4.	0,8	15	0,258	10	0,779	0,787
5.	0,9	15	0,258	10	0,839	0,835

According to Table 2, it is evident that time is directly proportional to distance. As the distance increases, the time required to cover that distance also increases (Giancoli, 2014).

Based on the results of the time calculation using the formula, there is no significant difference. This difference can be caused by human factors when using the tool.

Based on the calculation of time using formulas and the resulting graph, it can be concluded that the Arduino Nano-based physics laboratory tool for uniformly accelerated motion (UALM) can be used by students as a learning medium.

CONCLUSION

This research has successfully produced a design of a physics laboratory tool based on Arduino Nano sensors to analyze the phenomenon of uniformly accelerated motion (UALM). After undergoing several feasibility tests, it is stated that this Arduino Nano sensor-based laboratory tool can now be used as a learning medium. The results of the experiment to test the feasibility of using Arduino Nano as a demonstration tool for Uniformly Accelerated Motion (UALM) yielded two outcomes. In the first experiment, when the time and angle varied, the graph indicated that time is inversely proportional to the angle. On the other hand, in the second experiment, when the time and distance varied, the graph indicated that time is directly proportional to the distance (Abdullah, 2016).

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