THE APPLICATION OF ATWOOD MACHINE AND TRACKER ANALYSIS FOR CLASSROOM PURPOSE IN UNDERSTANDING RECTILINEAR MOTION

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Abstract
This study examines the kinetics of rectilinear motion in Atwood machines, with a specific emphasis on nonaccelerated and uniformly accelerated motion. The experimental configuration entails an Atwood machine equipped with a meticulously calibrated system, which includes a motion tracker for accurate data acquisition. During the study of the initial trial, we observed unanticipated shifts from consistent acceleration to nonaccelerated motion, which posed a challenge to our initial hypotheses. The interaction between forces and gravity in successive trials unveiled intricate dynamics, which enhanced the comprehension of the experimental system. The impact of extra masses on the acceleration of the hanging mass was methodically investigated. The results demonstrated a clear relationship between the mass of the extra load and acceleration. As each additional mass was added, the time it took for the first mass to reach the light gate decreased. The careful manipulation of time intervals yielded distinct observations on the influence of extra masses on the overall dynamics of the Atwood machine. These findings not only enhance our fundamental comprehension of forces and motion but also provide a helpful pedagogical tool for physics learners. The research elucidates the complex correlation between extra masses and acceleration, establishing a basis for further investigation and theoretical enhancement in the field of rectilinear motion.
Keywords: Rectilinear motion, atwood machine, tracker analysis, forcesure

INTRODUCTION

The science education curricula in Indonesia have been continuously enhanced via the introduction of a curriculum that promotes freedom to learn. However, the latest survey shows that the students must be challenged to improve their 21st century skills. Research shown that learning science managed by teachers cannot meet expectations due to less practical skills (Andrews et al., 2023; Braaten & Sheth, 2017). Proven by a report released by the OECD (2023) states that the 2022 Program for International Student Assessment (PISA) Survey was conducted to measure achievement in mathematics, reading, and science performance in students aged 15 years in survey participating countries. The results were as predicted, namely a sharp decline in student performance (steep learning loss) globally in the three disciplines tested: mathematics, reading, and science over the last four years since 2018 to 2022. This is worse than before, when in 2018, Indonesia occupies a lower position than other countries and is also in the lowest position when compared to countries in

Southeast Asia, especially Indonesia's scientific performance ability score of 396, which is in the lower rank of 71 out of 79 countries (OECD, 2019). In most cases, teaching science in Indonesia is primarily done in the classroom using only accompanying books, and students are less involved in actual activities. If we want the achievement of learning objectives and a deep understanding of students, the students must be involved in the learning process (Dwiyanti et al., 2021; Hamdani et al., 2022; Kamdi et al., 2022).

Science learning cannot be achieved through the monotonous repetition of information or by just listening to the teacher's explanations of topics. However, students must acquire knowledge by hands-on experimentation, careful observation, and active engagement, which will ultimately foster creativity and awareness (Andrews et al., 2023; Darling-Hammond et al., 2020; Wangchuk et al., 2023). This will enable them to better understand and enhance natural occurrences, thereby cultivating an understanding of science (Suryawati & Osman, 2018). Practical learning methods can shape students' ways of working and thinking because students actively participate in the process of observing, analyzing, and investigating objects. Practical learning activities are a form of activity that instructs students to be confronted as well involved in research or investigation activities. Marton (1988) stated that descriptions of what students learn are as important as descriptions of how they learn. This should be defined recursively in that both have structural (how) and referential (what) aspects. Experimental activity can enhance students' creative thinking (Fauziah et al., 2018) and students' critical thinking (Hajjah et al., 2022). Laboratory activity is the most important thing in learning science. It appears that neither curriculum developers nor teachers agree that science courses need to involve a substantial amount of laboratory work (Hodson, 1988). The essence of scientific endeavour is in the approaches employed to tackle challenges. The same thought had been proposed by Prosser and Millar (2016) that learning in a discipline such as physics involves more than changing conceptions (Prosser & Millar, 2016). In this work, the work will further discuss the importance of practical work to make meaningful learning. The experiment developed was focused on Grade 11 senior high school students in Merdeka curriculum.

Explicitly, the purpose of the subject is focus on the student's ability to solve some problems (Lestari et al., 2022). However, motion learning still faces many difficulties. Seeing this condition, we took the initiative to develop practical work that can help teachers in school identify the measurement of non-accelerated motion and uniform accelerated motion. This can be solved through practical exercise. Practical exercises and laboratory work are essential components of the educational process for students (Estriegana et al., 2019). There are many technologies that has developed, especially in science learning. One of the technologies that has been developed is Tracker Video Analysis. The findings indicate that Tracker has proven to be a valuable instrument in facilitating the experimental process and has the potential to enhance students' achievement of learning outcomes related to the issue under investigation (Fahrunnisa et al., 2021). The research conducted before has demonstrated that Tracker may be effectively used for the kinematics analysis of a rolling object on an inclined plane (Prima et al., 2015; Utari & Prima, 2019). According to Prima et al. (2015), the study indicates that Tracker video analysis is capable of meeting the needs of 80% of the students. However, there is currently a lack of studies that employ trackers in teaching rectilinear motion as an alternate tool for students to use in experimental activities. Hence, the uniqueness of this study lies in employing Tracker software to analyze rectilinear motion in an Atwood machine and assess its kinematic characteristics. Unlike the typical method which requires manual use of a timer, a tracker is capable of measuring the movement of an object in milliseconds, resulting in more precise data for analysis.

Consequently, learning activities are not only based on theory and formulas but an experiment can be carried out for students to understand the motion process better and measured using manageable equipment such as atwood machines and also tracker software.

This paper contributes to developing a motion experiment to measure the nonaccelerated motion and uniform accelerated motion combined with technology for classroom purpose. Students are also taught to be able to assemble an Atwood machine and also create and analyze the results of experiments in graphic form. This is of course in line with the basic competence required in the topic of rectilinear motion in grade 11. In particular, we also show the relationship between the additional mass of the object and the velocity.

METHOD

This research was carried out using the developmental research method to develop a new way of analyzing practical work on rectilinear movements. Developmental research is a type of research that focuses on the aim of developing, expanding and exploring further a theory in a particular scientific discipline. This research was conducted for 4 months starting from September to the last week of December. The practicum is designed to modify the additional load on the hanging initial mass so that students can see its effect on changes in rectilinear motion, speed and acceleration experienced by objects, either before or after passing through the light gate.

Principle of Atwood Machine

The acceleration of an object depends on the net applied force, and the mass. In a Atwood's Machine, the difference in weight between two hanging masses determines the net force acting on the system of both masses. This net force accelerates both of the hanging masses; the heavier mass is accelerated downward, and the lighter mass is accelerated upward.

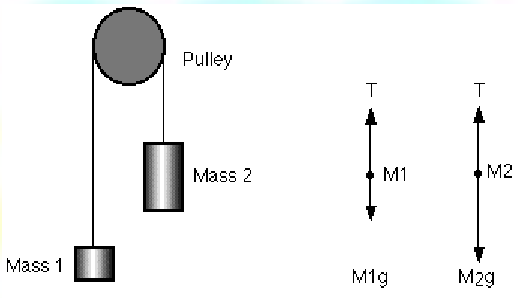

Figure. 1. The mechanism of atwood machine (a) xxxxxxxxxx, (b) xxxxxxxxxx

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Materials and Apparatuses

This research needs several materials and apparatuses as shown in Table 2.

Table 2. Materials and apparatuses

Materials	*Apparatuses*
1st Initial masses (M1), 100 grams	Atwood Machine
2nd Initial masses (M2), 100 grams	Pulley

4 Additional masses, 5 grams in each	Load driver Load strapping light gate Stopper straightness regulator Tripods Camera

This study used the newest version of Tracker video analysis which Tracker 6.1.5 (Oct 2023) for Windows. The software was accessed on physlets.org/tracker/.

Variables

This experiment contains 3 kinds of variables which are independent, dependent, and controlled. Those variables are detailed in Table 2.

Table 3. Experiment variables

Variable	*Details*
Dependent	The velocity in y-component (Vy) per second.
Independent	Amount of additional mass (5g each chip) and the height of the initial mass.
Control	The amount of intial masses, m1 and m2.

Based on previous understanding, this study initially postulated that increasing the additional mass added to the original mass would result in a greater force exerted on the beginning mass, leading to a faster acceleration. Another conjecture pertains to the light gate. Once the mass crosses the light gate, the acceleration will reach zero since there is no further increase in mass. Therefore, the motion will transition from nonaccelerated motion to uniform accelerated motion. However, the actual phenomena and trends will be substantiated and elucidated by the conduct of the experiment.

Procedure

The subsequent research procedures are illustrated in the accompanying flowchart.

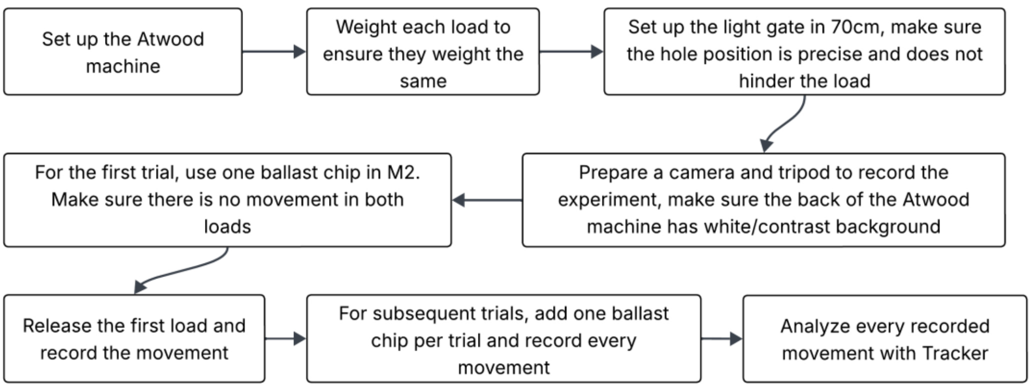

Figure 2. The flowchart of the procedure

The experiment was carried out 4 times with different additional masses. In the first experiment, one ballast chip of additional mass was placed, with the next experiment adding one additional mass, until the fourth experiment. When the masses move, the motion will be recorded and analyzed using Tracker Video Analysis. To make it easier to imagine the experimental setting, the following is the design of the experimental setting shown in Figure 3.

Figure 3. Experimental setting illustration

Figure 4. Real experimental setting

Figures 3 and 4 depict the visual representation of the experimental setup and the actual perspective captured by the camera. Once the car's motion for each turn is recorded, the video will be exported to Tracker for analysis utilizing automatic tracking. Prior to doing the automated tracking, it is imperative to calibrate the video by accurately determining the distance for the layout video during recording. The output of the automated tracking system will include the calculation of the duration of each movement, the distance traveled by the initial mass over time, and the velocity of the mass over time. The data collected from the tracker will be processed in Excel to create a time-distance graph and a time-velocity graph. The time-velocity graph yields the equation for both acceleration and deceleration. Therefore, the acceleration and force resulting from each turn of the car may be assessed.

Principles of Rectilinear Motion

Rectilinear motion is the movement of an object in a straight line. Unidirectional motion refers to the movement of an item in a single dimension, such as horizontally, vertically, or along an inclined plane, without any deviation from a straight path. Rectilinear motion, in the context of an Atwood machine, specifically denotes the straight-line movement of masses. The Atwood machine is a rudimentary apparatus comprised of a pulley and two masses linked by a string that traverses over the pulley. The masses undergo vertical displacement, and their motion can be analysed in a linear fashion. In a scenario of nonaccelerated motion, the masses on both sides of the pulley are of equal magnitudes, and there is no overall force generating acceleration. Here, the system is in a state of equilibrium, and the masses are moving at a consistent pace. The masses experience balanced forces, leading to rectilinear motion characterised by a constant speed.

If the masses on either side of the pulley have different magnitudes, a resultant force is exerted on the system. As a result, the masses experience an increase in velocity. The motion remains rectilinear, but it is now distinguished by consistent acceleration. The direction of the acceleration is contingent upon the relative mass of the objects involved. The greater mass will have a downward acceleration, whereas the lighter mass will undergo an upward acceleration. This is named the Uniform Accelerated Motion. The formula provided below:

(1) First equation

$$v = u + at$$

Where u is an initial speed

(2) Second equation

$$s = \frac{(u + v)}{2}\, t$$

(3) Third equation

$$s = ut + \frac{1}{2}\, at^2$$

(4) Fourth equation

$$v^2 = u^2 + 2as$$

Both scenarios include the movement of masses in an Atwood machine, which may be examined using classical mechanics principles, considering the forces, masses, and accelerations at play. This platform offers a pragmatic and informative opportunity to comprehend rectilinear motion, as well as the concepts of equilibrium and acceleration in a dynamic system.

RESULT AND DISCUSSION

Tracker Analysis

Before we set up the atwood machine, we will weigh each component which will be used to calculate other factors that will influence the movement of the mass. The results were tabulated as follows:

Tabel 4. Measurement result

Object	*Measurement*
Initial hanging mass	100 g
Additional mass (ballast chip)	5g
Plexyglass pulley	12mm
Atwood pole	150cm

After setting up the Atwood machine and ensuring that the camera equipment was prepared, the experimentation phase began by methodically adding masses. The original bulk descended in a regulated manner, coming to an immediate halt upon hitting the stopper. The brief duration of this process served as the reference point for subsequent tests. Importantly, Before the mass touches the stopper, the mass will first pass through a light gate which will hold additional mass so that the masses of mass 2 and mass 1 are the same. This precise arrangement was designed to simplify the process of comparing rectilinear motion. Every experimental session produced kinematic data recorded by a high-resolution camera, which was crucial for the following video analysis using Tracker, as depicted in Figure 5.

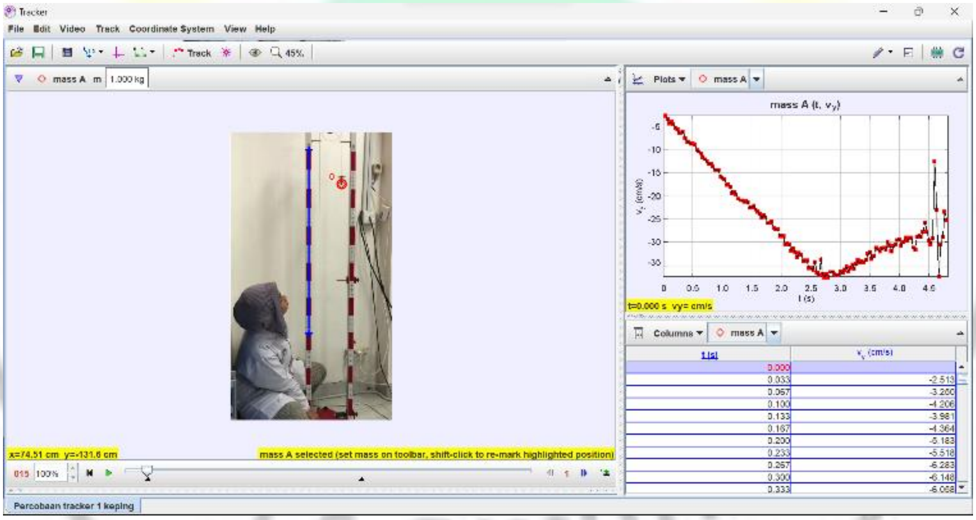

Figure 5. Analysis on Tracker Video Analysis

The collected video sequences were thoroughly analyzed utilizing Tracker software to derive valuable data on the movements of the masses in the Atwood machine. By varying the amount of additional masses (ranging from one to four), we observed and measured differences in the kinematic behavior. The meticulous examination, made possible by the integration of accurate equipment configuration and sophisticated video processing methods, enhances our comprehension of the mechanics involved in both nonaccelerated and evenly accelerated rectilinear motion inside the Atwood machine system.

The Velocity in y-component (Vy) per Second

The y-component velocity (Vy) denotes the object's vertical position change rate per unit of time. It measures the rate at which an item is travelling vertically, either upwards or downwards, with respect to time, and is often given in units of distance per second.

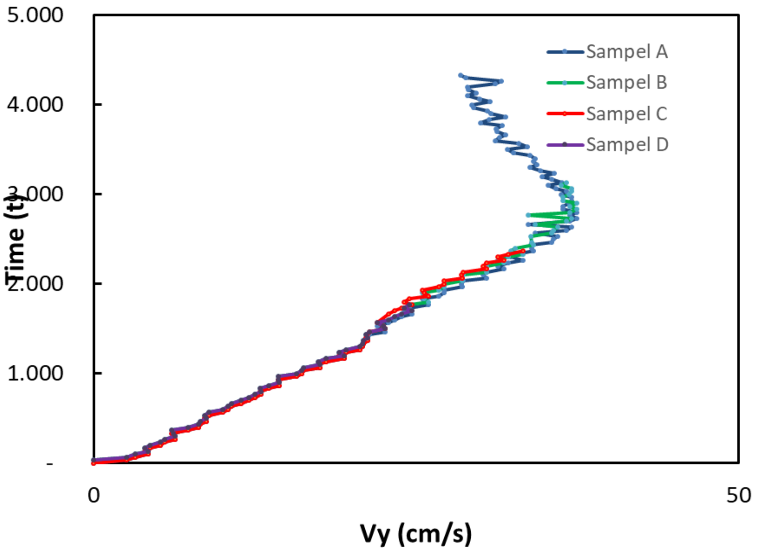

Figure 6. Analysis on Tracker Video Analysis

In order to analyze the reason behind the phenomena that occur on the acceleration results, teh analization for each experiment will be determined. As shown in figure 7,the initial trial involved careful examination of the extra mass, which was effectively carried out employing Tracker video analysis. According to the data, the mass passing through the light gate took around 2.8 seconds. As a result, the additional mass became stuck in the gate, making the initial mass equal to its counterpart (mass1). The graphical representation showed that there was ongoing acceleration, which contradicted the first hypothesis that predicted a shift from uniform accelerated motion to nonaccelerated motion after removing the excess mass. Remarkably, the graph displayed a momentary period of consistent velocity in milliseconds before transitioning back to consistent accelerated motion. This observation leads to a more detailed analysis of the applied forces and gravitational influences that contribute to the dynamic behaviour of the system.

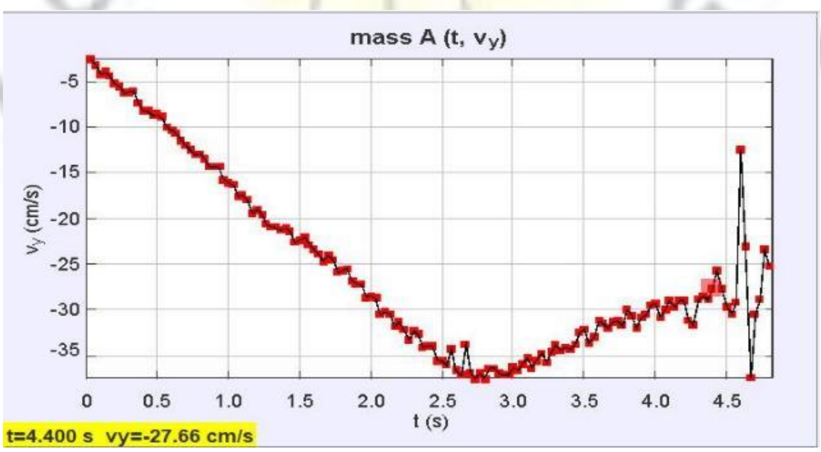

Figure 7. Analysis of 1 additional mass on Tracker Video Analysis

Additional understanding of the forces and gravitational impact provides clarity on the unanticipated changes in motion noticed during the experiment. The interaction between applied forces and gravity reveals complex dynamics, which challenge the basic assumption of a simple transition from uniformly accelerated to non-accelerated motion. A comprehensive comprehension of these forces establishes the basis for enhancing theoretical frameworks and models, crucial for deciphering the intricacies involved in the interaction between forces and motion in the experimental configuration. This in-depth examination enhances the overall understanding of the dynamics of rectilinear motion in the context of the Atwood machine system.

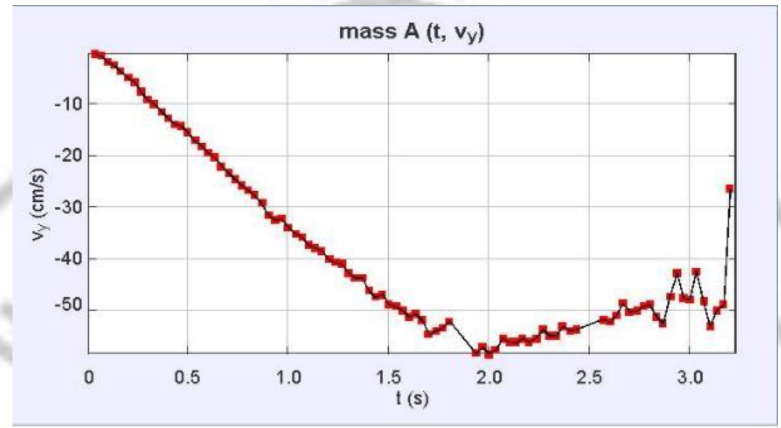

Figure 8. Analysis of 2 additional masses on Tracker Video Analysis

In the following experiment, a similar pattern became evident in the data, as shown in Figures 8, 9, and 10. The observed variance is specifically related to the duration it takes for the initial mass (mass2) to pass through the light gate. Adding a heavier mass to the starting mass caused a correspondingly greater acceleration, resulting in a faster transit through the light gate when the excess mass was removed. The gradual increase in the number of additional masses intensified this effect, causing the initial mass to reach the light gate approximately 5 seconds faster for each additional mass. In the initial experiment, which involved only one more mass, the recorded time was 2.8 seconds. In the second trial, there was an exact interval of two seconds. The third trial lasted 1.5 seconds, and the last trial, which included four additional masses, lasted around 1 second. This consistent fluctuation demonstrates how the extra masses have a noticeable impact on the motion of the suspended mass, affecting its acceleration and overall dynamics.

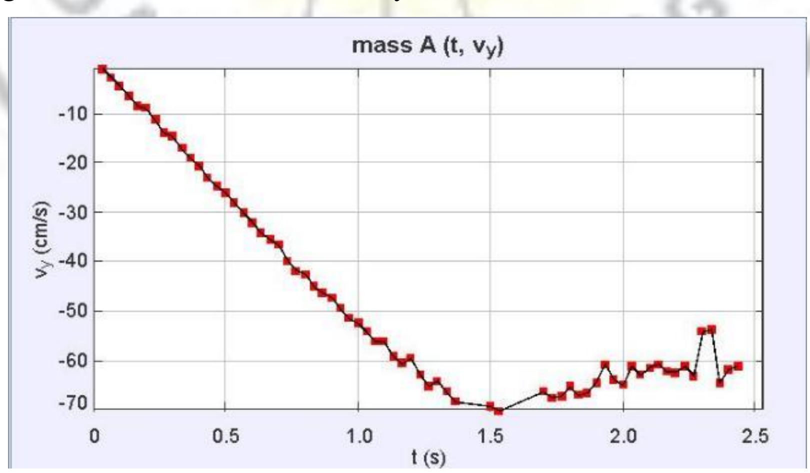

Figure 9. Analysis of 3 additional masses on Tracker Video Analysis

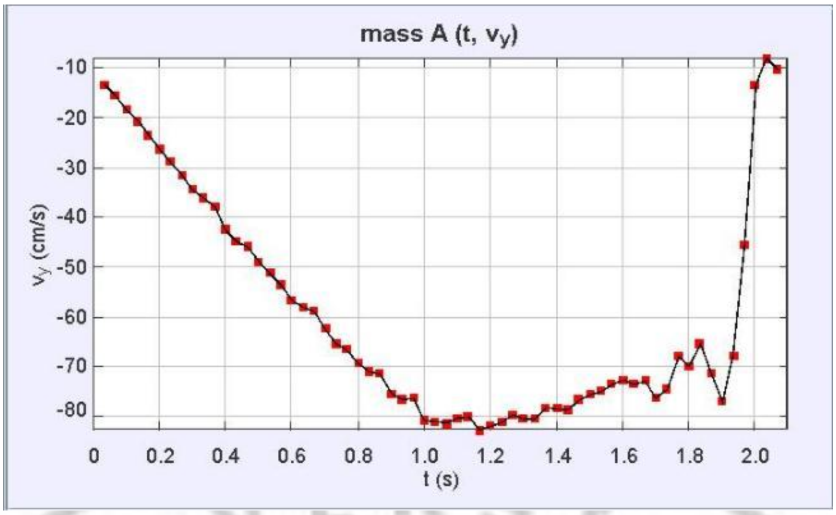

Figure 10. Analysis of 3 additional masses on Tracker Video Analysis

The systematic analysis of these tests highlights the clear relationship between the mass of the added load and the consequent acceleration, revealing a constant pattern of shorter time intervals as the mass increases. The observed effect of adding extra masses to the hanging mass's motion emphasizes the importance of mass ratios in determining the dynamic behavior within the experimental configuration. These findings offer vital insights into the complex correlation between new masses and the acceleration of the Atwood machine, laying the groundwork for further investigation and comprehension of forces and motion in this setting.

CONCLUSION

Nonaccelerated motion to uniform accelerated motion has been successfully analyzed using the Atwood machine and Video Tracker Analysis. However, the results obtained contradict the initial hypothesis proposed. The results show that the greater the number of additional loads on the initial mass, the greater the acceleration and force, thus making the load reach the light gate faster in proportion to the amount of additional load. Meanwhile, in the initial hypothesis, it was predicted that after the load passed through the light gate, there would be a change in motion from nonaccelerated motion to uniform accelerated motion. This is because the additional mass is trapped in the light gate, making the two initial masses have the same mass. However, what happens after the mass passes through the light gate is that it remains nonaccelerated motion. This can be seen from the graph of the movement of objects which does not show constant motion.

The experimental design in this research can be applied by students and teachers in learning force and motion material. To get accurate results, there are several things that need to be considered, including the quality of the camera used to record the experiment, guidance to students when carrying out the experiment, analyzing the data, and assembling the Atwood machine. Extra care is needed to avoid misunderstandings and get good results, and the materials used and calculations in making the car must be taken into account. Future research can apply different independent variables such as the difference in height in the two initial masses and also analyze whether there are other influences such as different pulleys which will give different results or not.

ACKNOWLEDGEMENT

This research is not supported by any funding from formal institutions or person.

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