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Development of an Atwood aircraft practicum tool based on automatic timers to explain Newton's second law

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Abstract. The aim of this study was to determine the feasibility of automatic time-lapse-based Atwood aircraft tools to explain Newton's second law. The method in this research was the experimental method. Instrument testing was carried out at mass loads m_1 of 0.01 kg, 0.02 kg, 0.03 kg, by using weights m_2 of 0.1 kg at a distance 60 cm and force variations of 0,5 N, 0,6 N and 1 N. The results of the measurement and analysis of the data obtained acceleration in theory Newton's second law, namely each for mass variants and successive forces is 4.864 m/s², 4.102 m/s², 3.414 m/s², 2.069 m/s², 2.581 m/s² and 4.102 m/s². The results of the acceleration calculation are based on an automatic time interval 4.220 m/s², 3.826 m/s², 2.985 m/s², 1.697 m/s², 2.415 m/s² and 3.826 m/s². The smallest error data is 6.39% and the biggest error is 18%. The results of these measurements indicate the measurement is still accurate because the error percentage is less than 20%.

1. Introduction

The activity of the laboratory is one of the methods used in the teaching and learning process that provides direct opportunities for students to find and understand concepts through observation and experiment [1]. Laboratory activities are very necessary and can be approved in the physics learning process because physics is essentially built from a unity of aspects of scientific products and processes [2].

The problem that is often encountered in school for implements physics learning integrating laboratory activities. The main problem in the implementation of laboratory activities in schools is the unavailability of practical facilities and infrastructure in the laboratory and also the ability of teaching staff in conducting laboratory activities [3]. Laboratory facilities and infrastructure are not only about the building of the laboratory but also about the facilities available in the laboratory such as practical tools [4]. Besides, the factor for buying tools is expensive, making these tools not available in school laboratories [5]. One of the best solutions available for solving this problem, one of which is innovating practical materials that use materials that are easily found in the surrounding environment and are cost-effective.

Newton's second law is one concept that must be learned by students. Newton's second law is used as a basic concept in understanding other physics concepts [6]. The concept discussed is explaining how the motion of an object is influenced by the total force acting on the object [7]. The characteristics of Newton's laws are very unique to be learned in the learning process, this concept is easy to convey, but

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if students do not understand the concept well it will cause errors, difficulties, and even misconceptions [8]. This is caused by several factors including students only remembering the statement of Newton's laws and mathematical equations without understanding the physical meaning of these laws. As a result, students' problem-solving abilities are reduced and cause errors in solving Newton's laws problems [9].

The research about Newton's second law has used animation learning media. The media can attract and increase student interest in learning. But in the media, there is no answer key for the evaluation question [10]. As a result, students do not know how to elaborate on the problem being worked on, other than that if students do not practice directly then students will easily forget the concept based on the facts that have been described, researchers seek to improve students' understanding of the concept of Newton's second law by using the activities of the laboratory. Students are not only able to master concepts but also can develop skills about how to build their own concepts with activities of the laboratory [11,12].

One of the tools that can be used to do Newton's second law activities of the laboratory is the Atwood plane. Atwood aircraft is a physics tool introduced by British scientist George Atwood (1746-1807) [13]. This tool consists of two load systems which are initially at rest and then connected to a slippery pulley using a lightweight rope [14]. Because slippery pulleys and rope mass are ignored, the tension of the rope is the same at each point [15]. The working principle of this Atwood plane is when the mass of the object m_1 and the mass of the object m_2 is equal $(m_1 = m_2)$ then both will be stationary. When the mass of object m_1 is greater than the mass of object m_2 $(m_1 > m_2)$ then the mass of object m_2 will be attracted by the mass of object m_1. Conversely, if the mass of an object m1 is smaller than the mass of an object m_2 $(m_1 < m_2)$ then the mass of m_1 will be attracted by the mass of an object m_2 [16]. When moving mass of the first object and mass of second object experiences the same acceleration but in the opposite direction [17].

Some research on the Atwood design was developed using an automatic timer using a light-sensitive sensor (phototransistor). When the load is blocking the first sensor and the second sensor mounted on the stative the sensor will record and stop the time taken by the object automatically. The smallest scale of this timer is 0.01 seconds [12]. While other studies were developed based on PIR (Passive Infrared) sensors. This sensor is passive, only responds to the energy of the passive infrared light that belongs to any object that is detected by it. The tool of aims to determine the value of the earth's gravitational acceleration and compare it with the agreed value of the earth's acceleration [18].

Both of these studies have drawbacks in terms of the costs required to make this tool still expensive. The initial force given varies. So, the impact results in the accuracy of the data obtained. The novelty of the research developed an Atwood plane that has the same functions and ways of working, but by using an automatic timer and adding automatic load movers to avoid the initial force differences given. Besides, the cost of making Atwood is cheaper and simpler. The teachers can make and use it themselves.

2 Methods

The method used in this study was the experimental method. The main components used are Arduino Nano, 5-12 volt adapter, DC dynamo, and three pushbuttons. Arduino nano is used as an automatic timekeeping feature, the adapter is used to provide voltage so that it can turn on and move the dynamo, and the dynamo is used to provide the initial force to be able to release objects on the pulley and three pushbuttons that function as starting time, stopping and reset of the tool.

The working principle of Newton's second law laboratory activities using the Atwood plane is to put two pieces of load connected by a rope and use two variations. The use of variations in mass where the first load as a force is worth 1 N at one end of the rope and as a fixed variable. Then the other end is given a load of 10 grams, 20 grams, and 30 grams, alternately. Besides force, it is necessary to ensure that the length of the track is fixed at 60 cm. The record of measured time for each load. As for variations in force using worth 0.5 N, 0.6 N, and 1 N with a fixed mass of 20 grams and a fixed track length of 60 cm.
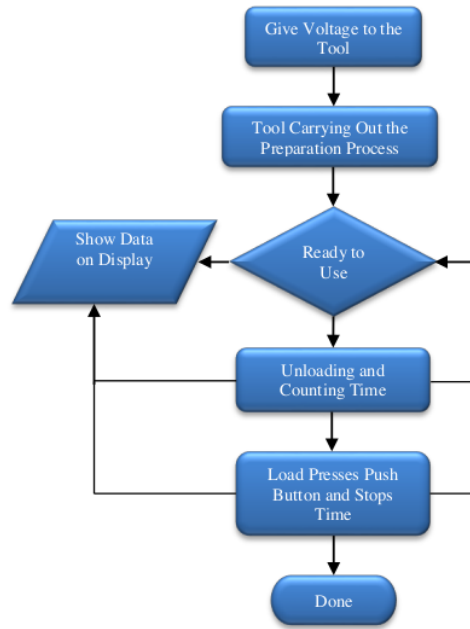
Figure 1. Atwood aircraft design.

Figure 2. Flowchart tool usage.

The data obtained in the form of time taken by the load then processed to determine its acceleration using a review of straight motion changes irregularly. Straight motion changes irregularly are the motion of an object on a straight line with constant acceleration [19]. The case of constant acceleration, the equation applies as follows:

$$v = v_0 + at \tag{1}$$
$$x = v_0 t + \frac{1}{2}at^2 \tag{2}$$
$$v^2 = v_0{}^2 + 2a\Delta x \tag{3}$$

Based on the equation, the equation used to determine the acceleration value is [20].

$$a = \frac{2\Delta x}{t^2} \tag{4}$$

Then compare with the theory equation using Newton's second law which states that the acceleration of an object is directly proportional to the total force acting on it and inversely proportional to its mass [21]. The equation is:

$$\sum F = m \, a \tag{5}$$

Where a is the acceleration, m is the mass and $\sum F$ is the total force [22]. By reviewing his style diagram, the acceleration value experienced by objects in the pulley system is given by:

$$a = \frac{(m_2 - m_1)}{(m_1 + m_2)} g \tag{6}$$

The rotation of all points on the object surrounds the object's axis or axis [23]. When an object rotates will have the rotational inertness of the object with respect to that rotational axis. This inertia depends on the particular axis of rotation that it surrounds the shape and the mass dispersed within the object. The moment of pulley inertia with m_k masses forming circular plates show in the equation

$$I = \frac{1}{2} m_k r^2 \tag{7}$$

If friction is ignored, the acceleration of a load is done by:

$$a = \frac{(m_2 - m_1)}{(\frac{1}{2}m_k + m_1 + m_2)} g \tag{8}$$

From equations 7 and 8 above, we can find the value of acceleration in theory according to Newton's second law and calculation through a review of straight motion changes irregularly. The percentage of tool errors obtained with equation 9.

$$Error = \left| \frac{a_{theory} - a_{count}}{a_{theory}} \right| x 100\% \tag{9}$$

3. Results and discussion

Atwood aircraft-based laboratory tool has been made that starts with designing then making the tool. The tool is equipped with an automatic time sensor that uses Arduino nano as an automatic timekeeping feature. When the load presses the push button it will detect the sensor automatically generate the time indicated on the display. There are two variations of data made from the laboratory using the Atwood-based automatic time gauge in the form of mass variations and force. Table 1 shows the average results of time measurement data with the varied mass.

Table 1. The results of the time obtained by objects on mass variations.

Mass (kg)	Time (s)
0.01	0.533
0.02	0.560
0.03	0.634

The fixed variables in the data collection are 1 N force and 0.6 m long of load transfer. The three masses used have a different time to move as far as 0.6 m. Mass of 0.01 kg takes 0.533 s as the shortest time of the three variations of mass used and mass of 0.03 kg needs 0.634 s as the longest time when viewed from the three loads.

Table 2 shows the acceleration value based on Newton's second law for moving objects in a fixed pulley system.

Table 2. Acceleration value for mass variation.

Mass (kg)	t_{timer} (s)	a_{theory} (m/s^2)	a_{Count} (m/s^2)	Error (%)
0.01	0.533	4.864	4.220	15.26
0.02	0.560	4.102	3.826	7.21
0.03	0.634	3.414	2.985	14.37

If data table 2 is illustrated in a graph, it can be seen the relationship between mass and acceleration. Figure 3 shows the link between mass and acceleration.
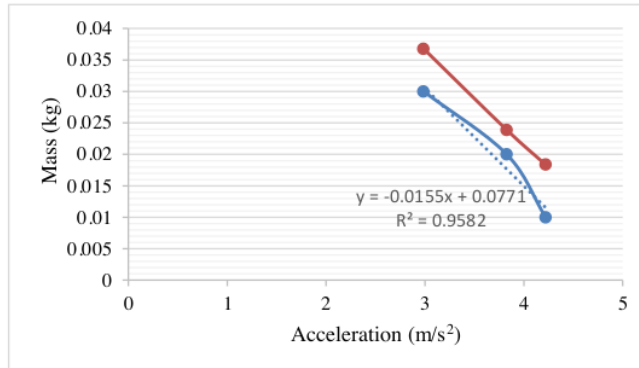
The blue line in figure 3 shows the relationship between mass and acceleration based on experimental results using a review of straight motion changes irregularly. For example, objects having a mass of 0.01 kg, the acceleration they experience is 4.220 m/s^2. Objects with a mass of 0.03 kg have an acceleration of 2.985 m/s^2. Thus, it can be seen that the smallest mass objects have the highest acceleration and vice versa. The blue line on the graph shows the relationship between mass and acceleration has an inverse relationship.

The next review is using Newton's second law theory which is illustrated by the orange line in figure 3. The orange line illustrates the ideal state that should occur if the object has an acceleration of 4.220 m/s^2, the ideal mass is 0.018 kg. This situation will be linear with an acceleration of 3.826 m/s^2 with an

ideal mass of 0.023 kg and an acceleration of 2.985 m/s² with a mass of 0.036 kg. However, the orange line on the graph shows the inverse relationship between mass and acceleration.

Figure 3. Relationship of acceleration and mass.

There is a significant difference between the blue line stating the relationship between mass and acceleration based on experimental data with the orange line which is a review of Newton's second law for the relationship between mass and acceleration in ideal circumstances. The highest error occurred at a mass of 0.01 kg of 15.26%. Surely the resulting error can be caused by several factors such as the reduced elasticity of the rope used on the Atwood plane, the friction between the rope and the pulley being ignored, and the initial velocity caused by the dynamo dc in the neglected circuit. So, there needs to be an improvement in these things in order to minimize errors of measurement on the tool. Overall both the blue lines and orange lines in figure 3 show similarities in the relationship between mass and acceleration, that both are inversely proportional. Therefore, the Atwood plane tool can be used for Newton's second law laboratory activities with the mass being variable of variation.
The measurement of the variation in force and the average time obtained showed in Table 3.

Table 3. The result of time obtained by the object in the variation of force.

Force (N)	Time (s)
0.5	0.533
0.6	0.560
1	0.634

Experiments carried out for variations in force using fixed variables, namely the load transfer as far as 0.6 m and the mass of objects valued at 0.02 kg. Based on Table 3 can be seen that the 0.5 N force has the shortest amount of time that is 0.533 s to move as far as 0.6 m in the laboratory activities. When the 1 N force takes 0.634 s. So, when a large load the time needed to move is getting longer, on the contrary when the load is light, the time needed to move will be shorter.

Table 4 shows the acceleration values based on experimental results with varying force. The calculation of these data uses Newton's second law for moving objects in a fixed pulley system.

Table 4. Acceleration value for force variations.

Force (N)	t_{timer} (s)	a_{theory} (m/s^2)	A_{count} (m/s^2)	Error (%)
0.5	0.841	2.069	1.697	18.00
0.6	0.705	2.581	2.415	6.39
1	0.560	4.102	3.826	6.73

If table 4 is illustrated in a graph, it can be seen the relationship between force and acceleration. The following graph is the linkage between force and acceleration.
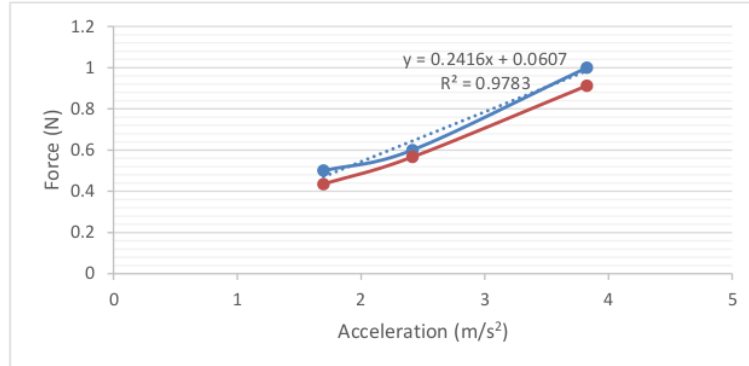

Figure 4. Relationship of acceleration and mass.

The blue line shows the relationship between force and acceleration based on experimental data using the Atwood aircraft based on an automatic timer. When the force used is 0.5 N, the acceleration produced is 1.697 m/s^2. The greatest force variation is 1 N and the resulting acceleration is also the highest acceleration value in the experimental variations of force that is 3.826 m/s^2. The showing the line formed by the relationship between force and acceleration is directly proportional to each other. The greater the value of the force, the acceleration is even greater, and vice versa.

Newton's second law states that the relationship between acceleration and force is directly proportional. This situation is illustrated in the graph using orange lines. Calculations using Newton's second law equation become an ideal state review to find out the relationship between force and acceleration. The orange line shows that when the acceleration produced is 1.697 m/s^2, then the force that should be applied is 0.43 N, acceleration of 2.415 m/s^2 requires a force of 0.56 N, and acceleration of 3.826 m/s^2 has a force of 0.91 N. These values are ideal conditions with a displacement of 0.6 m and a load mass of 0.02 kg. When viewed from the orange line formed, acceleration and force have a directly proportional relationship. This shows the suitability of the experimental results with Newton's second law theory. The difference seen from the two lines on the graph is not very significant, but at an acceleration of 1.697 m/s^2, there is a significant error of 18.00%. The factors that cause errors have been explained in the previous section when explaining the relationship between mass and acceleration.

Experiments using variations in mass and force using Atwood's tool are in accordance with Newton's second law theory. This Atwood tool has the advantage that the circuit used is simpler but has the same functions and working principles. In addition, this tool is also cost-effective in the manufacturing process because tools and materials can be found easily. Besides, this tool is designed in such a way that there is no external force that can cause increased errors in the measurement results by installing a DC motor driver/dynamo in the circuit. It's just that there are still shortcomings, that still have an error value. the use of this laboratory tool, the smallest error is 6.39% at the time of review of force variations with a fixed mass, and the largest error of 18% also occurs when the force review is at a fixed mass. This error can be a benchmark for the accuracy of the Atwood aircraft with an automatic timer that has been developed. The error resulting from the acceleration calculation result is caused by several factors including the mass of the rope which is neglected as well as the length of the rope, there is a possibility of the initial speed experienced by the load, and the load did not directly press on pushbutton when it reaches the cross-section of the tape.

10 Conclusion

The results of the study and discussion it can be concluded that the Atwood aircraft equipment has been made with an automatic time-lapse recorder using Arduino nano. The results of calculations for acceleration are carried out using a varying mass of 0.01 kg, 0.02 kg, and 0.03 kg and load variations of 0.5 N, 0.6 N and 1 N. The automatic timer tool works well, this is shown through the results of the acceleration calculation manually approaching the calculation in theory. The smallest error data is at 6.39% and the largest error data is 18.00%. Thus, this tool can be implemented to explain Newton's second law to students at school.

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