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STEM-Integrated Phyphox to Enhance Student Engagement and Understanding of Newton's Law

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Abstract

The COVID-19 pandemic has significantly impacted educational technology, such as virtual labs, simulations, and various learning software, to facilitate physics experiments. In the post-pandemic era, virtual laboratory continues to be used in hybrid and face-to-face learning. However, virtual laboratories lack the practical skills of students compared to hands-on experiments. Phyphox (Physical Phone Experiment), an open-source tool that utilises mobile device sensors, addresses the problem by integrating students' practical skills. This study examines the integration of Phyphox in STEM-based physics learning, with a focus on Newton's Laws. Using an exploratory sequential mixed methods approach, the research examines how Phyphox can enhance student engagement and understanding of complex physics concepts. The first phase involves designing and implementing experiments related to Newton's Laws using Phyphox, while the second phase tests the application in authentic learning contexts. The study employs pretests, post-tests, and questionnaires to evaluate the effectiveness of this approach. Results indicate that STEM-based learning integrated with Phyphox significantly improves student learning outcomes and engagement. Students reported positive experiences, highlighting the app's ease of use, accurate data, and ability to make learning more interactive and enjoyable. The research sample consists of two experimental classes from grades XI Senior High School 1 Karanganyar, with 33 students per class, selected via a Cluster Random Sampling method from the school's overall population. The findings suggest that integrating Phyphox into physics learning can provide valuable guidance for teachers, students, and researchers to develop more effective and engaging STEM education methodologies.

Keywords: Phyphox, Physics, STEM, Engagement, Understanding

INTRODUCTION

The COVID-19 pandemic has brought significant challenges for educators and students, especially with the abrupt shift to online learning, which has required the development of effective teaching strategies (Ametepe & Khan, 2021; Klein et al., 2021). This change has dramatically impacted physics learning, which is heavily dependent on direct experimental activities. To overcome this, various platforms and technologies such as mobile devices, virtual labs, virtual simulations, video analysis, and remote labs are beginning to be explored as solutions to allow physics experiments to continue in an online format (Anindhyta et al., 2021; Berlianti et al., 2021; Mafudi & Handhika, 2021; Ropawandi et al., 2022; Velentzas et al., 2024).

The transition to hybrid and face-to-face learning requires a change in teaching methodologies (Susanti et al., 2023). Even though the COVID-19 period has passed, virtual laboratory simulations are still used as a medium for practicum learning in face-to-face sessions in the new normal or post-pandemic period (Yanto et al., 2022). This transition continued during the adjustment period when in-person classes resumed (Dewi, 2023). While virtual simulations successfully overcame many obstacles in physics learning during the pandemic, they have an inherent limitation: they cannot provide direct practical experience. This fact highlights that the essential aspect of hands-on experimentation remains crucial and constitutes a gap left unfilled by purely virtual methods. Hands-on experience conducting experiments is essential for deepening your understanding of physics concepts (Zacharia & Olympiou, 2011; Lakka et al., 2023). By taking advantage of existing technological developments, experimental practices can be integrated with digital technology to create a more immersive and interactive learning experience (Baxter & Hainey, 2023; Paramita et al., 2024). One of the innovations in this field is the Phyphox (physical phone experiments) application.

Phyphox is an open-source application that utilises the internal sensors of mobile devices for a variety of physics experiments, having been available since September 2016 (Staacks et al., 2018). This application has proven to be an engaging and beneficial tool for experimentation because it allows students and teachers to creatively and innovatively utilise raw sensor data, even facilitating integration with platforms like Arduino (Putri et al., 2023). Furthermore, Phyphox is free of charge and capable of generating and storing data from previous experiments (Sari et al., 2023). Consequently, Phyphox provides a substantial opportunity for both students and teachers to explore various concepts in physics and natural sciences more deeply using mobile technology.

Integrating STEM (Science, Technology, Engineering, and Mathematics) education with Phyphox can provide students with hands-on experience of physics concepts through interesting experiments. Integrated STEM education is an interdisciplinary approach that combines all four STEM disciplines as a whole, with a primary emphasis on one STEM subject, connecting two or more domains of STEM knowledge through STEM practice in a natural context to enhance students' understanding of interdisciplinary relationships between STEM disciplines (Sulaiman et al., 2023). STEM is currently a focus of attention across many countries, establishing it as a key educational trend (Cheng et al., 2022; Teo et al., 2022; Liu, 2023; Wang, 2023). STEM encourages students to become problem-solvers, inventors, and innovators by cultivating the mindset of an engineer and a scientist, thereby building independence, confidence, logical thinking skills, technological literacy, and connecting learning outcomes to the professional world (Zimmerman, 2016; Promboon et al., 2018; Jazuli, 2021). Given the inherent advantages of Phyphox, its integration with the STEM approach will make learning significantly more engaging than using Phyphox in isolation.

STEM-based learning is an approach that integrates Science, Technology, Engineering, and Mathematics. This approach creates a relevant and applicable learning process where students understand natural phenomena (Science) using technology, design solutions (Engineering), and analyse data (Mathematics) (Utami et al., 2023; Hanif et al., 2019). Through this integration, students can understand concepts holistically and apply them in real-world problem-solving.

Newton's laws are one of the main foundations of mechanical physics (Avinandan & Mandal, 2020). Physics learning is a way of thinking, investigating, gathering knowledge, and interacting with technology and society (Chiappetta & Koballa, 2010). In mechanics, students learn how objects move and the underlying laws that govern them. Newton's laws, formulated by the great scientist Sir Isaac Newton, explain the fundamental relationship between force, mass, and acceleration and form the basis for understanding the motion of objects in this world (Erfan & Ratu, 2018). While previous studies have confirmed that the STEM approach significantly improves student learning outcomes in topics such as Newton's Law (Utami & Nurlaela, 2021), a crucial gap in the literature remains regarding the utilisation of real-time measurement technology. Specifically, no investigation has systematically tested the STEM-Phyphox Integration in this context. This limitation presents a strong scientific urgency to fill this void. By integrating Phyphox, students can conduct direct Newton's Law experiments, which we hypothesize will simultaneously Enhance Student Engagement and Understanding.

This study will explore how integrating Phyphox applications in physics learning can facilitate a deeper understanding of Newton's Laws. This research will examine how Phyphox can be used in various physics experiments related to these laws and how this technology can improve student engagement and facilitate understanding of complex physics concepts. This research can make a positive contribution to efforts to improve STEM education in innovative and engaging ways. By providing research methodologies, findings, and implications of integrating Phyphox into physics learning, this study will provide valuable guidance for teachers, students, and researchers interested in developing more effective and engaging STEM education.

METHODS

This study uses an exploratory sequential mixed-methods approach, integrating qualitative and quantitative data collection and analysis across two sequential phases (Dawadi et al., 2021; Munce et al., 2021). The first phase, the qualitative phase, focuses on designing learning and experiments that explore and develop experimental activities related to Newton's Law using the Phyphox application. The second phase, the quantitative phase, aims to test the application of the design results in real learning contexts.

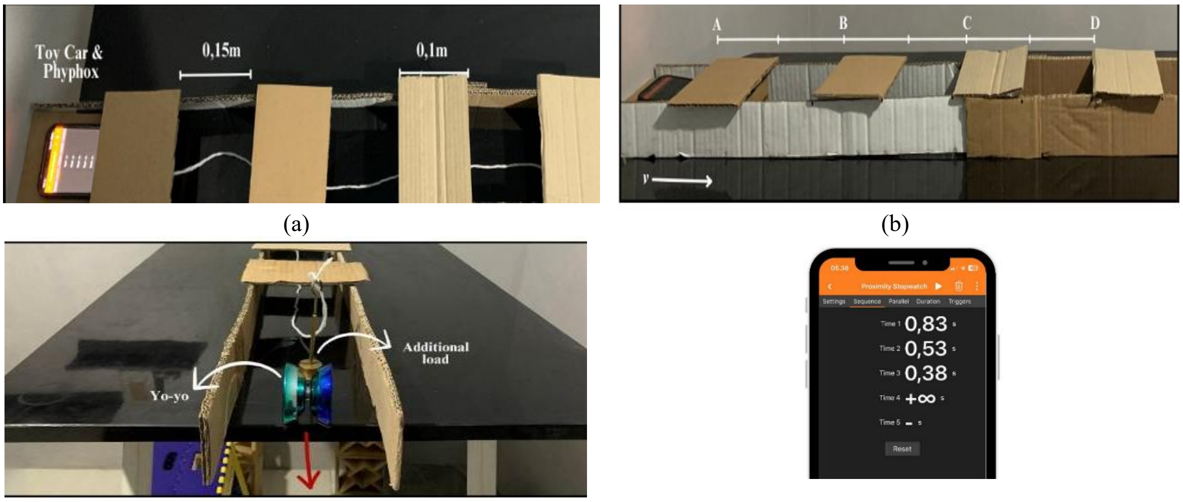
Qualitative Phase

The qualitative phase focuses on the design of learning and on implementing experiments that explore and develop activities related to Newton's Law. In this phase, researchers apply a STEM-based learning approach to integrate various aspects of science and technology into the learning process. The exploration was conducted through an in-depth study of the application of STEM learning in physics using the Phyphox app. This application will help students understand physics concepts more practically and interactively. The researcher also analysed how Phyphox works, its features, and its use in physics experiments to improve students' understanding of Newton's Laws. The findings from this exploration serve as the foundation for designing innovative learning experiences relevant to students' needs, including adjustments to measurement instruments and the design of experiments integrated with technology.

Newton's 2^{nd} Law Experimental Design

This experiment aims to observe the effects of movement when a mass is exerting influence. This experimental design relates to the application of Newton's Second Law, as shown in FIGURE 1. In this experiment, a toy car was modified by placing a piece of cardboard on top of a smartphone. The vehicle will move along a straight track 0.15 meters wide, arranged about 1.2 meters long on a table with a height almost equal to the length of the track. To connect the car to the load, a rope is used and pulled across the end of the table. At the end of the table, there is a yo-yo, as shown in FIGURE 1(c), which functions as a pulley so that it does not get caught between the car's towing rope and the edge of the table, so that the load can fall freely without the influence of friction. On the track, several points are equipped with 0.1-meter crossing bridges separated by 0.15 meters, as shown in FIGURE 1(a) and FIGURE 1(b). This bridge is a sensor cover for a smartphone connected to the Phyphox application.

In addition, a proximity sensor is available that can serve as a photogate timer when an object is nearby. This means that the proximity sensor, typically used to detect the presence or distance of an object, can also be utilised as a timing mechanism similar to a photogate (Carroll & Lincoln, 2020). When things approach the sensor, it triggers a timing event, making it a convenient and practical alternative to traditional photogates. This feature measures the time needed to travel in sequence from one point to another, as shown in FIGURE 1(d).



(a) (b) (c) (d)

FIGURE 1. The experimental design for Newton's 2nd law is given. (a) The toy car will slide towards the right due to the pull of the dropped load. (b) Four bridge points will provide three data on travel time from one point to another. (c) A yo-yo is given to facilitate the rope movement between the toy car and the additional load. Red arrows indicate the direction in which the m2 load dropped. (d) Display of the proximity stopwatch feature in the Phyphox application.

For simplicity, let us define the mass of the toy car as m_1 and the mass of the additional load dropped as m_2. The effect of force on the motion of this body will be observed by varying m_2 five times (0.06 kg, 0.07 kg; 0.08 kg, 0.09 kg, 0.1 kg) using a gravitational acceleration of 9.8 m/s^2. When m_2 falls due to the Earth's gravitational force, it will be followed by the motion of the toy car. After the trial set is ready, the toy car will slide as a rope pulls it, and the sensor will measure the time sequentially.

The proximity sensor will start measuring when it detects an object in front of it (in this case, it is a dark area). Time measured is the time it takes to move from one dark point A) to the next dark point B), as shown in Figure 1(b), and this time is defined as the travel time from point A to B, called t_{AB}. The sensor then continuously measures the time from the second dark (point B) to the third dark (point C), called t_{BC}. The sensor takes time measurements until it reaches the last dark spot, as shown in FIGURE 1(c). It is important to note that this time is the travel time between two points. For example, t_{AB} is the time it takes to travel the distance s_{AB}. The distance between point A and point B (s_{AB}) is the sum of the cover's width and the length between the two covers, which is 0.25 meters. This is equal to the distance between the other two points, or it can be written as $s_{AB} = s_{BC} = s_{CD} = 0.25$ meters. This measurement will obtain the magnitude of the force, distance, and travel time between two points for each force variation, with m1 remaining constant.

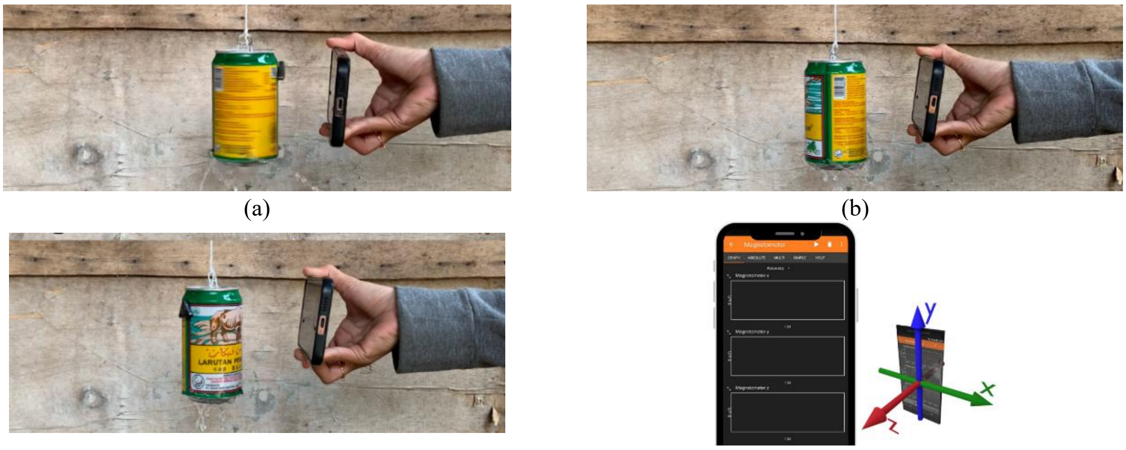
The same step is used to find the relationship between an object's mass and acceleration, but it varies by m_1. The total mass on m_1 is the sum of the mass of the toy car, the smartphone, and the mass of additional loads added. However, because the mass of the toy car remained constant, the m_1 variation in this experiment was the mass of the extra load, which was varied five times (0.01 kg, 0.02 kg, 0.03 kg, 0.05 kg, 0.06 kg). Currently, the m_2 value remains constant at 0.08 kg.

Newton's 3rd Law Experimental Design

The experimental design used to investigate Newton's 3rd Law is shown in FIGURE 2. This experiment uses the magnetometer feature in the Phyphox application to detect magnetic fields. Three beverage cans have been punctured with nails of different diameters and tied with a string to their seals. Magnets are attached to the top of the cans to detect their movement. The holes in each can are initially closed, possibly using fingers, and the cans are filled with water until complete. Ensuring the holes are tightly sealed is essential to prevent water leakage.

Magnetic field measurement in Phyphox begins when the lids of the cans are removed. After that, the cans will rotate in the opposite direction to the previously created holes. This process is carried out alternately on the three cans, and the obtained data can be compared. This experiment is designed to have the magnets in each can create a magnetic field, which is then measured using the magnetometer, as shown in FIGURE 2(d).

A magnetometer allows for measuring moving or rotating objects of ferromagnetic materials (Carroll & Lincoln, 2020). In the context of this experiment, the same concept is used by using a magnetometer to detect the rotation speed of a beverage can. In this scenario, the rotational speed of the beverage can be estimated by evaluating the peak of the magnetic field graph over time, which corresponds to the number of rotations indicated by the Phyphox application.



(a) (b) (c) (d)

FIGURE 2. Experimental design to explore Newton's 3rd law. (a) The first frame shows the condition of the magnet near the smartphone sensor. (b) The second frame depicts the rotating can during the measurement process. (c) The third frame illustrates the condition where the magnet on the can is positioned far from the sensor. (d) Display magnetometer features in the Phyphox application and the coordinate system.

Quantitative Phase

The second phase, the quantitative phase, aims to test the application of the design results in real learning contexts. During this stage, experiment-based learning using Phyphox is implemented in the classroom, followed by data collection from students through pretests, post-tests, and questionnaires. The cluster random sampling method was employed to select two experimental classes from all eleventh-grade (Class XI) classes at SMA Negeri 1 Karanganyar, by dividing them into several clusters. The random selection of these clusters (classes) aims to ensure the research findings reflect the population's variation, thereby making the conclusions more relevant to the overall population (Thomas, 2023). Experimental class I uses STEM-based learning integrated with the Phyphox application, while experimental class II uses STEM-based learning without the Phyphox application. Each class consists of 33 students.

Before and after the treatment, students took a pre-test and post-test consisting of 20 multiple-choice questions. These tests had been rigorously assessed for reliability (Kuder Richardson coefficient of 0.893) and validity (construct and content) to measure the increase in their knowledge. The validation results of 20 multiple-choice questions showed that all questions were declared valid, although minor revisions were needed for some designers. These findings show that the overall problem has been effectively measured in aspects relevant to the learning objectives. The same questions are used on both tests to ensure consistency of measurements. In addition, a questionnaire was also given to evaluate students' responses to the applied learning design.

Prequisite Test

The prerequisite tests were carried out using the homogeneity test and normality test. The data analysed in this test are the values of the pretest results of experimental classes I and II. The homogeneity test was carried out using the Bartlett method with the following hypothesis: H_0 states that both classes (samples) come from homogeneous populations. In contrast, H_1 states that both classes (samples) come from non-homogeneous or heterogeneous populations. Meanwhile, the normality test uses the Lilliefors method, with the H_0 hypothesis stating that the sample is usually distributed and H_1 stating that the sample is not normally distributed.

Balance Test

The balance test used a paired *t*-test to compare the average of two measurements in the same group, namely the experimental class I, before and after the treatment. The data used includes the values of pretest and post-test results. The hypothesis proposed is as follows: H_0 states that the starting and ending abilities of the first experimental class are balanced. In contrast, H_1 states that the starting and ending abilities of the class are not balanced.

Comparison Test

Student responses were analysed by calculating the average of the overall response scores, then classified according to the category in TABLE 1 (Ouahi, Hassouni & Ibrahmi, 2023). The comparison test was conducted using One-Way ANOVA (Analysis of Variance) to compare the average of more than two groups based on one independent variable. The data used included the post-test results from the experimental classes I and II. The hypothesis proposed is as follows: H0 states no difference in ability between groups, while H1 states that there is a difference in ability between groups.

TABLE 1. Categorisation of student questionnaire responses to the Phyphox application

Scale	Interpretation of Results
Between 4.21 and 5.00	Very positive
Between 3.41 and 4.20	Positive
Between 2.61 and 3.40	Neutral
Between 1.81 and 2.60	Negative
Between 1.00 and 1.80	Very negative

Questionnaire

The questionnaire aimed to determine students' perspectives on using the Phyphox application during Newton's Law experiments in the classroom. The questionnaire consists of 16 indicators that aim to measure students' responses to using the Phyphox application (Ouahi et al., 2023; Putri et al., 2023), where students provide assessments based on the Likert scale with a range of values from 1 to 5. The indicators asked in the questionnaire can be seen in TABLE 2.

TABLE 2. Questionnaire and student responses

No	Indicator
1	I feel motivated to do practicum activities using the Phyphox application.
2	I am interested in using the Phyphox application in other practicum activities.
3	I prefer to do experiments using the Phyphox app instead of conventional measuring tools.
4	The measurement results generated in graphs and tables from the Phyphox application are of good quality (scale and numerical readability).
5	The graphs and tables downloaded from the Phyphox app helped me understand the concepts of Newton's Laws.
6	All navigation and menus in the Phyphox app are easy to operate.
7	The features in the Phyphox app are well-structured so that I can differentiate between the types of experiments.
8	I was able to retrieve accurate experimental data by using the Phyphox app.
9	I don't need any unique tech expertise to use the Phyphox app.
10	I didn't experience technical issues like crashes, stuttering, or hangs when using the Phyphox app.

No	Indicator
11	Experimenting with the Phyphox app made the lessons on Newton's Laws even more enjoyable.
12	Conducting experiments using Phyphox increased my interest in studying physics.
13	The Phyphox app gives me a new learning experience I wouldn't get in a conventional setting.
14	I love the Phyphox app because I can do it anywhere with different gadgets.
15	I am satisfied with the use of the Phyphox application in physics class.
16	Experimenting with the Phyphox app helped me understand Newton's Law material better.

RESULTS AND DISCUSSION

Exploration Results

Newton's 2nd Law Experiment

The first step will focus on investigating the relationship between acceleration and force. Based on the experimental design shown in Figure 1, the first experiment was conducted to find the relationship between acceleration and force by varying the variable m_2. When m_2 falls downwards, gravity acts on it. Then, data is obtained from TABLE 3, which shows the time interval at four specific points.

TABLE 3. Categorisation of student questionnaire responses to the Phyphox application

m_2 (kg)	F (N)	t_{AB} (s)	t_{BC} (s)	t_{CD} (s)
0.06	0.588	0.64	0.44	0.35
0.07	0.686	0.65	0.45	0.33
0.08	0.784	0.57	0.36	0.28
0.09	0.882	0.40	0.27	0.21
0.10	0.98	0.40	0.25	0.19

Using the relationship between distances (s) and travel time (t), we can find out the velocity (v) of each movement from one point to another using EQUATION (1).

$$v = \frac{\Delta s}{\Delta t} \quad (1)$$

Starting at rest, the change in velocity can be calculated for each increase in time in the data set. This velocity can be presented as a graph of the relationship between velocity and time, as seen in FIGURE 3.

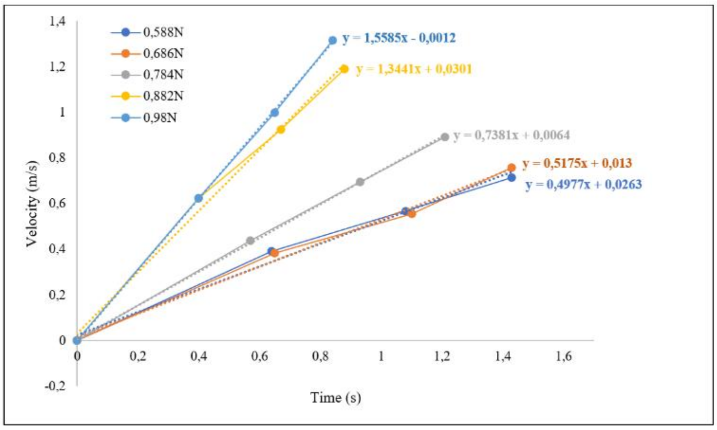


FIGURE 3. Graph the velocity versus time relationship for each force variation

The acceleration can be calculated from the slope of each line (Quadling & Gilbey, 2016). Therefore, the relation between forces and accelerations is represented in FIGURE 4.

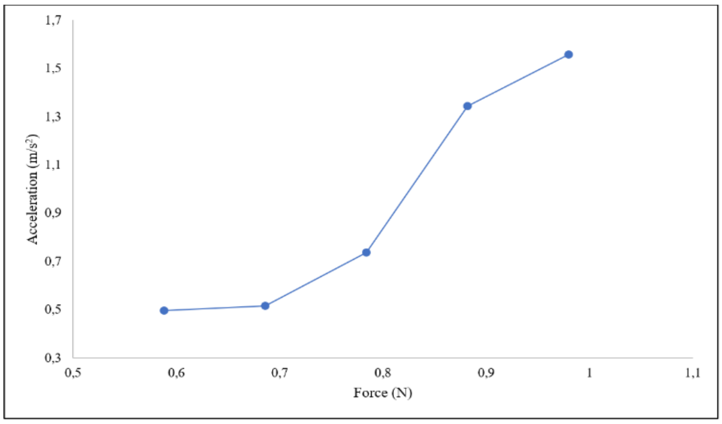


FIGURE 4. The acceleration versus force graph shows the relationship according to Newton's 2nd Law

Overall, the trend of the force-acceleration chart is rising. The system's acceleration will also increase proportionally when the applied force increases. Essential physics explains this relationship through Newton's Law, which states that the resultant force acting on an object is proportional to the acceleration experienced by that object. When a large force is applied, the resultant force increases and the system's acceleration increases. In other words, the graph depicts the system's compliance with the basic principles of physics described by Newton's 2nd Law, as seen in EQUATION (2). This shows the consistency between the experiments conducted and existing theories and provides a clearer understanding of the relationship between force and acceleration in the context of these experiments.

$$F = ma \tag{2}$$

The slope of acceleration-force should be constant. However, FIGURE 4 explains that each line has a different gradient. For 0.784 N and 0.882, the slope reached a maximum. Meanwhile, other gradients show almost the same. Using the more significant force difference is suggested, and the minimum force is more excellent than 0.588 N for the same experiment. Furthermore, consider the height of the track to the ground and the track length because it will impact the constant force needed to pull the toy.

The next step involves exploring the relationship between acceleration and mass. The experimental data for the second case are shown in TABLE 4 and then presented in a velocity versus time graph in FIGURE 5. The velocity gradient versus time is described as an average acceleration shown in the relation between mass and acceleration in FIGURE 6.

TABLE 4. Categorisation of student questionnaire responses to the Phyphox application

m_1(kg)	t_{AB} (s)	t_{BC} (s)	t_{CD} (s)
0.01	0.67	0.40	0.30
0.02	0.70	0.42	0.35
0.03	0.65	0.47	0.35
0.05	0.83	0.53	0.38
0.06	0.85	0.52	0.40

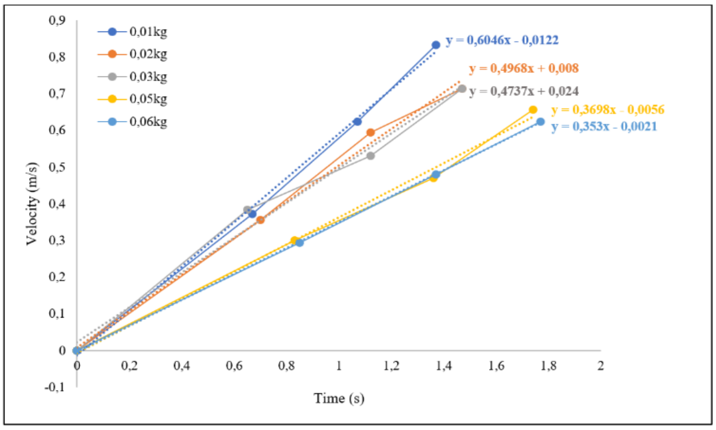


FIGURE 5. Graph the velocity versus time relationship on each variation of the m_1 value for the force

From the analysis, it was found that there is an inverse relationship between the mass and acceleration when the forces are the same. When the mass of the system – the additional load – increases, there is a decrease in the system's acceleration. This decrease occurs because of the larger mass contained in the system. The greater the force required to achieve the same acceleration. The basic principle of Newton's 2nd Law is consistent with these findings. It indicates that the system's acceleration is inversely proportional to its mass, as shown in EQUATION (2). In other words, if the mass of the system is increased, the acceleration of the system will be correspondingly reduced**.**

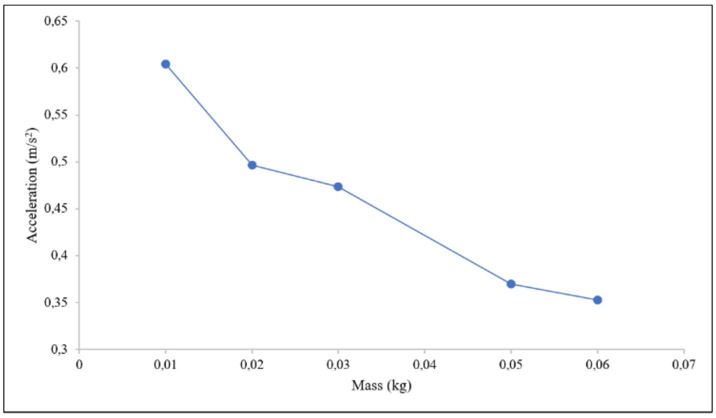


FIGURE 6. The acceleration versus mass graph shows the relationship according to Newton's 2^{nd} Law

Experiments analysing Newton's Second Law have evolved with technological advancements. Prior studies, such as Rakestraw et al. (2023), designed experiments leveraging the Phyphox application's accelerometer on mobile phones to study force and acceleration. Conversely, other classic experiments utilise specialised, expensive equipment like electronic counters, crystal oscillators, and photogates to measure time and acceleration for gliders on a track (Hessel et al., 2013). The fundamental advantage of Phyphox integration lies in its capacity to provide precise measurements with minimal cost and high accessibility. Experiments utilising the proximity sensor within Phyphox are significantly superior as they eliminate the need for complex and costly laboratory hardware and do not demand specialised expertise in electronics. This makes Phyphox an ideal tool for STEM-based physics education.

Newton's 3^{rd} Law Experiment

Measurement data from the magnetometer sensor in the Phyphox application can be exported to Excel after exporting the data. Magnetic field and time graphs can be analysed and interpreted to generate the graph shown in FIGURE 7.

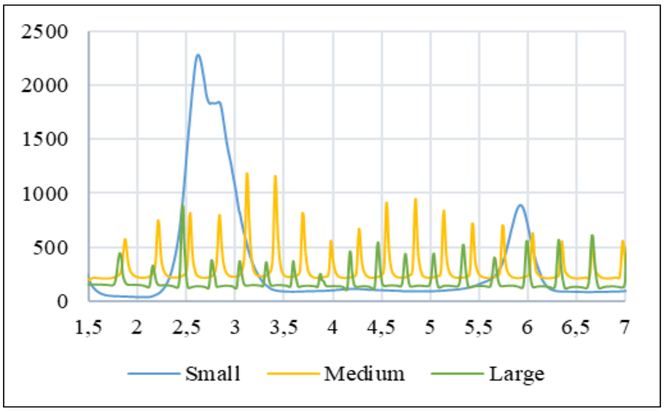


FIGURE 7. A graph that combines the magnetic field values measured on the magnetometer with the increase in time on the three existing cans

The peak in FIGURE 7 indicates a strong magnetic field, meaning the magnet on the can is close to the sensor, while a small magnetic field value suggests the magnet is farther away. The rotational motion of the can affects the magnet's proximity to the sensor, and the number of spins can be calculated from the peaks between 1.5 and 7 seconds. The first can, with a small hole, spins once, while the second (medium-sized hole) and third cans rotate eighteen times. This data demonstrates how the water force affects the number of rotations (centripetal force). A small hole creates a weak force, making it difficult for the can to spin. In contrast, medium-sized holes produce a stronger force, allowing the can to spin faster. Although large and medium-sized holes result in a similar number of rotations, cans with larger holes rotate more quickly due to a shorter time to complete eight spins. This experiment illustrates Newton's Third Law: the action force exerted by the water on the can generates an equal and opposite reaction force on the water. Through this experiment, we gain a deeper understanding of Newton's Third Law, which explains the relationship between force and reaction, and how the water's force on the can affects its rotational motion.

Exploration of Newton's Third Law concepts can be conducted through time-consuming bottle rocket projects (National Geographic Society, 2014) or complex and expensive electronic experiments involving force sensors and carts (Antwi et al., 2020). However, using the magnetometer within the Phyphox application offers significantly more innovative and effective advantages. Phyphox is highly superior because it is simple, economical, and easily accessible, relying solely on the smartphone's built-in magnetometer sensor without requiring specialised hardware or advanced electronic expertise. The application plays a key role in STEM integration, allowing students to measure real-time changes in the magnetic field (Science & Technology), design the experimental setup (Engineering), and analyse the graphical data for quantitative validation (Mathematics). Thus, Phyphox is an inclusive and authentic platform for integrating all four STEM elements, effectively enhancing student engagement and understanding of Newton's Third Law.

To enhance the credibility and objectivity of the research results, we have strengthened the methodological foundation by deeply analysing the Phyphox data. The validity of the real-time data is ensured through sensor calibration and an optimal sampling rate. We also maintain transparency by acknowledging and minimising measurement errors and recognising the inherent experimental limitations (such as smartphone sensor variability or human error). This comprehensive approach renders the analysis of Phyphox's effectiveness in STEM learning more objective and insightful.

Implementation of Learning with Phyphox

In experimental class I, STEM-based learning with an integrated experiment of applying Phyphox on Newton's 2nd Law material was divided into six groups. The learning process began by displaying phenomena relevant to the material as a representation of science components (S). Furthermore, using the Phyphox during the experiment is an application of technology (T). Students are also asked to design experiments independently, which means they implement the engineering component (E). In this experiment, students have the freedom to vary the value of the variable according to the instructions listed on the worksheet. Students analyse the result data to conclude with a mathematical analysis involving a mathematical component (M) in the STEM approach.

In the experiment, the distance between the points was measured as the sum of the cover width and the distance between the covers, with a consistent value of $s_{AB} = s_{BC} = s_{CD} = 0.20$ meters. After obtaining the data, students conducted a mathematical analysis, which is crucial for reinforcing the mathematical aspect of STEM-based learning. The analysis of student data exploring the relationship between object acceleration and forces revealed that the average acceleration increased progressively from a smaller value to a larger one. This confirms that as the applied force increases, the acceleration of the car also increases proportionally, indicating a directly proportional relationship between force and acceleration. In contrast, in the second part of the experiment, which examined the relationship between acceleration and mass, the data showed that as the car's mass increased, the average acceleration decreased. This demonstrates an inversely proportional relationship between acceleration and mass (Dayana & Satria, 2023). Thus, it can be concluded that students successfully explored Newton's 2nd Law through STEM-based learning, utilising an integrated experimental design with the Phyphox application.

STEM-based learning with an integrated experiment using the Phyphox application to explore Newton's 3rd Law follows a method similar to the experiment on Newton's 2nd Law. In this activity, students are given the freedom to vary certain variables according to the instructions in the worksheet. These variables include the size of the holes in the cans with different nails and the time range to calculate the number of peaks or spins produced by the cans. Based on the student experiment, two cans with the same number of holes rotate under different conditions. Within 35 seconds, the Phyphox application showed that cans with larger-diameter holes rotated 42 times, while cans with smaller-diameter holes rotated 30 times. This demonstrates that the thrust produced by the water coming out of the hole in the can is equal to the centripetal force, represented by the number of can revolutions, in accordance with Newton's 3rd Law (Dayana & Satria, 2023). Therefore, it can be concluded that students have successfully explored Newton's 3rd Law through STEM-based learning, using an integrated experimental design with the Phyphox application.

Result and Analysis of Students' Responses

The results of the pretest obtained before the treatment and the post-test conducted after the new approach are summarised in full in TABLE 5.

TABLE 5. Summary of pretest and posttest results in both classes

Information	Pretest		Post-test	
	With Phyphox	**Without Phyphox**	**With Phyphox**	**Without Phyphox**
Average	49.849	44.242	74.242	65
Standard deviation	16.177	17.007	15.965	19.121
Min	25	20	40	20
Max	85	95	95	95

Prerequisite Test Result

In this study, data analysis was carried out twice, namely before and after the experiment. The analysis before the experiment was intended to see the balance of students' initial abilities in two classes. Several tests were carried out in the prerequisite analysis test with a significance level of 5% to ensure that the data used met the necessary statistical assumptions. First, the normality test using the Lilliefors method showed that the L_{cal} value for class I (0.153) and class II (0.131) did not exceed the L_{table} value (0.1542), which means that the data from both classes were usually distributed. Since the data is distributed normally, data processing continues by conducting paired sample t-tests (Afifah et al., 2022). Second, the homogeneity test using the Barlett test method produced a χ_{cal}^2 value of 0.0789, which was not more significant than the χ_{table}^2 value of 3.481, indicating that the data variance of the two classes was homogeneous. Therefore, the data from both classes meet the assumptions of normality and homogeneity, making them feasible for further analysis.

Balance Test Result

The results of the paired t-test analysis on pretest and post-test data after being given STEM-based learning treatment integrated with the Phyphox application showed that the t_{cal} value of -7.427 was smaller than the t_{table} of 1.669 at a significance level of 5%. The test results show that H_0 is rejected and H_1 is accepted (the initial and final abilities of the class are not balanced). This indicates a significant imbalance or difference between pretest and post-test data (Afifah et al., 2022). Before the treatment, the average pretest was 49.849, indicating the learners' initial ability before learning. After the treatment, the average post-test increased to 74.242, reflecting the learning strategies' positive impact. This significant improvement shows that STEM-based learning with experiments integrated with the Phyphox application effectively improves student learning outcomes.

Comparative Test Result

Before conducting the comparison test, a balance test was carried out using a t-test, which showed that the t_{cal} value of 1.653 did not exceed the t_{table} value of 1.669. This indicates that both classes have a balanced starting ability. Furthermore, the one-way ANOVA test analysis was done using an Excel application, as shown in TABLE 6.

TABLE 6. Summary of ANOVA one-way test analysis

Source	Nos	Sum	Average	Variance	F	p-value
Class 1	33	2450	74.24	254.877	4.5	0.037
Class 2	33	2145	65	365.625		

The results of the trial using post-test data from experimental class I (class 1) and experimental class II (class 2) showed that the p-value (0.037) was smaller than the significance level (0.05). Thus, the null hypothesis was rejected, meaning there is a difference in ability between the two groups. This difference shows that the two treatments have different effects on each class. Higher average post-test results were found in the first experimental class that used STEM-based learning integrated with the Phyphox app.

The Phyphox app allows students to design their own experiments, fostering creativity and improving teamwork, which in turn enhances their cognitive and creative thinking abilities (Dwi Fatmala et al., 2019). While simply reading data from sensors can help students learn data analysis, understanding the background of physics experiments and completing additional tasks can further improve their math skills (Imtinan & Kuswanto, 2023). Research by Awaludin et al. (2024) shows that some researchers have implemented STEM approaches without using applications like Phyphox. However, it has been proven that STEM significantly influences student learning outcomes in physics. These findings align with research by Azhar et al. (2022), which states that STEM-based learning increases student interest, positively affecting their physics learning outcomes. This indicates that integrating the Phyphox application provides a deeper understanding of Newton's Laws compared to a second experimental class that only uses STEM-based learning without Phyphox.

Questionnaire Result

The questionnaire was filled out by 33 respondents, namely students from the first experimental class who participated in STEM-based learning and conducted Newton's Law exploration experiments using the Phyphox application shown in FIGURE 8.

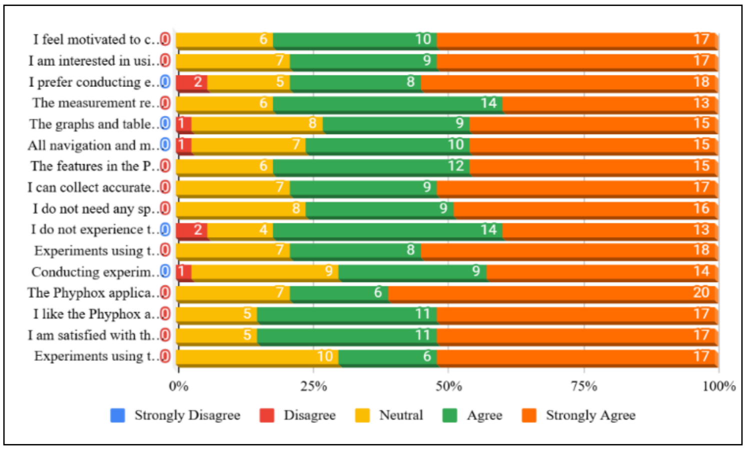


FIGURE 8. Distribution of student responses on questionnaires for each indicator

The questionnaire results completed by students after conducting physics experiments on Newton's Laws using the Phyphox application generally indicated a positive response. The measurement results presented by Phyphox in graphs and tables were considered high-quality, with accurate scales and easy-to-read numbers (average score: 4.212). Students also reported no technical issues such as crashes, lags, or freezes while using the app (average score: 4.182), suggesting that Phyphox is stable and technically reliable. Additionally, students found the app offered a unique and engaging learning experience not available in traditional settings (average score: 4.394). This aligns with their preference for using the Phyphox application over traditional measuring instruments (average score: 4.273). Features like charts, tables, and intuitive navigation helped students understand Newton's Laws more thoroughly. With its user-friendly features, accurate data, and flexibility, students viewed Phyphox as an effective tool for supporting physics learning, especially for understanding Newton's Laws and conducting experiments (Puspita Sari et al., 2022). The flexibility of Phyphox, which works across various devices and conditions, makes it a practical solution for physics experiments (Bura et al., 2022). The overall average score from the questionnaire was 4.267 out of 5.00, which falls into the very positive category (Ouahi et al., 2023). These results demonstrate that Phyphox has enhanced students' motivation, interest, and understanding of physics concepts, offering a more meaningful and efficient learning experience.

CONCLUSION

The findings of this study conclusively demonstrate that the STEM-based learning model, integrated with the application of Phyphox for teaching Newton's Laws, was successfully designed and effectively implemented. This success is evidenced by a significant increase in the average post-test scores within Experimental Class I. Furthermore, a comparative analysis of the post-test results between Experimental Class I (using Phyphox) and Experimental Class II (without Phyphox) confirms the superiority of the integrated method, showing a significant difference ($p = 0.0369$) with higher average outcomes recorded in the Phyphox-supported class. Student response to this learning approach was also highly positive, achieving an average questionnaire score of 4.267 out of a maximum of 5.00. Collectively, these findings affirm that STEM-based learning utilising the Phyphox application is effective in improving learning outcomes and is very well received by students. Consequently, this research provides a strong empirical foundation for future curriculum implementation that integrates smartphone technology into science education. It also offers crucial input for teacher training programs on adopting and leveraging digital tools like Phyphox to enhance the quality of Physics instruction.

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