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Smartphone for physics practicum in momentum and impulse

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Abstract: Practicum is an important part of Physics learning that cannot be ignored even in distance learning. Obstacles to practicum facilities faced by students can be overcome by using sensors on smartphones as a measuring tool. This study aims to use the accelerometer sensor on a smartphone to analyze the concept of momentum and impulse through the collision of two toy cars. The smartphone-assisted experimetal method was applied for this study. Two toy cars A and B with smartphones attached have their respective masses of m1 0.31345 kg and m2 0.32116 kg. Car A was idle and car B was moved until it collided with car A. In the event of a collision, the accelerometer sensor recorded acceleration data (a) versus time (t). Data (a) versus time (t) was represented in the form of a curve. Next, the data were analyzed. From the graph obtained data t1 =1.237 seconds, when car B started to exert a contact force on car A. The contact time between cars was dt = 0.025 seconds. The maximum acceleration experienced by car A during a collision was a = 27.919 m/s^2. From the area of the curve (a) vs (t), the impulse value was 0.1217 (N. sec) which is also the value of the change in momentum of car A, with car A's speed after the collision of 0.427 m/s. Thus, the accelerometer sensor on a smartphone can be used to assist students in finding important concepts through practical activities. The use of the accelerometer sensor is expected to help students to facilitate understanding of the concepts of momentum and impulse.
Keywords: Smartphone-Based Experiment; Physics Experiment; Momentum and Impuls; Low-Cost Experiment; Simple Experiment

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Introduction

Distance learning is a global issue that occurs during the Covid-19 pandemic, including in Indonesia. The government's policy in making distance learning decisions is an effort to prevent the spread of Covid-19 from getting wider. One of the distance learning systems that can be done is online learning. The online learning system is face-to-face online learning by a means of the internet network (Allo, 2020; Bahasoan et al., 2020; Giatman et al., 2020).

However, in online learning, teachers must ensure that the effectiveness of learning is well maintained, including practicum activities (Yusuf & Widyaningsih, 2020). Physics is a subject that cannot be separated from practical activities because they function to broaden students' thinking (Asamoah & Aboagye, 2019; Fidan & Tuncel, 2019; Hodson, 1990), improve understanding, develop science process skills (Serevina et al., 2018), and assist students in having problem solving skills (A. Y. Nuryantini et al., 2020; Shana & Abulibdeh, 2020)

To conduct practical activities, media in the form of tools and practicum materials are needed (Bakri et al., 2020; Wati et al., 2020). However, there are a few schools that do not yet have media for the practicum, such as the unavailability of laboratories and the lack of practicum tools. Meanwhile, in distance learning conditions, even though the school has a laboratory, students find it difficult to access practical tools at school. Therefore, the use of applications and sensors on smartphones owned by students is an alternative for conducting the practicum at home (Lellis-Santos & Abdulkader, 2020; Ade Yeti Nuryantini et al., 2021).

Smartphones have many applications and sensors that have been developed rapidly to help physics practicum activities (Klein et al., 2014; Kuhn & Vogt, 2012; Monteiro et al., 2015; Osario et al., 2017; Parolin & Pezzi, 2015; Pili & Violanda, 2018; Zakwandi et al., 2021). Among the available applications are Phypox and the physics toolbox. Phypox (https://phyphox.org/) and physics toolbox (https://www.vieyrasoftware.net/) integrate various sensors on smartphones and laptops that have the ability to perform measurement activities while doing practicum. Smartphone development as a practical tool often stands alone. This means that practicum activities have not been designed according to the characteristics of the learning process and the learning criteria by the curriculum. In fact, the development of practicum activities for the secondary school level must be in line with the demands of the curriculum.

Futhermore, this paper will present the use of the accelerometer sensor which is used to measure acceleration, contact time, determine impulses, and changes in momentum experienced by objects during collisions. Practicum activities are adjusted to the results of material analysis in the current Physics curriculum in Indonesia (K-13) and its relation to practical activities using the accelerometer sensor on a smartphone. Curriculum review is very important so that the implementation of learning remains in accordance with the competencies to be achieved in learning (Doyle, 1986). In addition, curriculum review can also assist teachers in developing lesson plans. By implementing smartphones as practicum tools in the physics learning, it is expected that it can help teachers build more effective and innovative learning processes to improve student learning outcomes in terms of cognitive, psychomotor, and affective.

Method

This research is experimental research by developing a simple experimental method assisted by smartphone. The initial stage is curriculum analysis which refers to the learning achievement for impulse and momentum topics. The results of the curriculum analysis are then used as a guided to explore the tools and experimental apparatus. The topic of impulse and momentum was selected because of the availability of sensors in smartphones that allow the implementation of the practicum. In addition, the sensors needed to carry out momentum and impulse experiments using smartphones are almost available for every type of smartphone. Besides, this practicum is also included in the basic practicum that must be carried out in high schools but is constrained by limited equipment.

After the curriculum analysis stage, an analysis of physics concepts that can be experimented is carried out. The physics concepts studied are impulse and momentum. The analysis of physics concepts serves as a theoretical reference in developing a smartphone-assisted experimental model. In addition, this stage also examines the specifications of smartphone sensors that may be used as measurement tools. The smartphone sensor used in the study is the accelerometer.

The last stage of this research is to take measurements. Measurements were made by designing a physics experiment with the aid of a smartphone sensor. Measurements were made to test the suitability of the experimental results with the concepts of momentum and impulse. The reseacrh procedure provide visually in Figure 1.

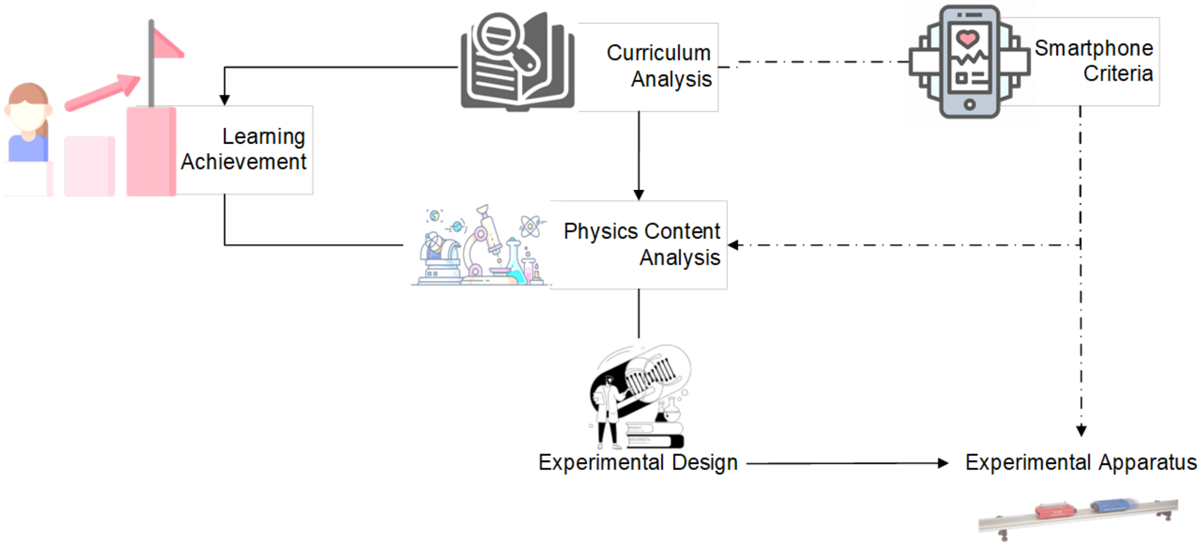

Figure 1. Research Procedures

Results and Discussion

Curriculum Analysis of Momentum and Impulse Materials in Relation to Practicum Using Smartphone Accelerometer Sensor

The core competencies (KI)/basic competencies (KD) Physics curriculum, momentum and impulse lessons are taught in 10th grade in KD 3.8 and 4.8. The content of KD 3.8 is applying the concept of momentum and impulse, as well as law of conservation of momentum in daily life. The content of KD 4.8 is presenting the result of experiment on applying the conservation law of momentum, for instance free fall ball to the ground and simple rocket. From those basic competencies (KD), practicum activity can be designed using accelerometer on smartphone with indicator in Table 1.

Table 1. Practicum design in accordance with KD 3.8 and 4.8

No.	Basic Competency Achievement Indicators	Practicum goals
1.	Analyzing the acceleration of an object experiencing a collision	Determining the **acceleration** of an object during a collision through **a** *vs t* graph from the data recoded by accelerometer on smartphone Determining the **time interval Δt** of objects during the collision through **a** *vs t* graph from the data recorded by the smartphone accelerometer
2.	Analyzing the change in momentum and velocity of the object after the collision from the area under the curve **F**- *t*	Determining the **magnitude of impulse** upon collision objects through F vs t graph from the data recorded by smartphone accelerometer. Calculating the **changes of momentum** object. Determining **object's velocity** after collision.
3.	Analyze the impulse of a force that changes versus time	Determining **the average effective force** F_{avg} that produces the same impulse as the force changes versus time from the data recorded by the smartphone accelerometer

Analysis of the K-13 curriculum indicates that students are expected to understand the topic of discussion about momentum and impulse both theoretically and experimentally. This is in accordance with studies that prove that the use of additional media such as simulations and interesting experimental activities can increase students' attention during learning. (Fang & Guo, 2022). Therefore, the implementation of practicum activities in learning must be pursued regardless of the availability of practicum facilities or not.

Table 1 indicates that there are at least 6 types of practicums that can be optimized for learning the topic of momentum and impulse. The types of practicums that can be optimized include acceleration, time interval, magnitude of impulse, the changes of momentum, object's velocity, and effective force. However, the implementation of the six types of practicums is quite difficult to implement using common practicum tools in schools. On the other hand, to produce precise measurements and demonstrate the concept well, relatively sophisticated equipment is required.

Concept Overview

The concept of momentum and impuls begin with the Newton's second law as seen in Equation 1.

$$\boldsymbol{F} = m.\boldsymbol{a} \tag{1}$$

By subtitute the Equation 2 into Equation 1, the Equation 3 is obtained.

$$\boldsymbol{a} = \frac{dv}{dt} \tag{2}$$

$$\boldsymbol{F} = m.\frac{d\boldsymbol{v}}{dt} \tag{3}$$

Using the simple calculation we obtain the Equation 4.

$$\boldsymbol{F}.\Delta t = \boldsymbol{I} = m.\Delta\boldsymbol{v} = \Delta\boldsymbol{p} \tag{4}$$

From the Equation 4, m.**v** or m.Δ**v** is known as momentum (**p**). The mathematical model in Equation 4 explained that momentum (**p**) is known as a measure of difficulty in stopping object's motion. Momentum is a vector quantity where **p** is momentum (kg. m. s-1), m is mass (kg), and v is velocity (m.s-1).

Every object that has a certain mass and motion will have momentum. The faster the object moves, the greater the momentum. The slower the object moves, the lesser the momentum. Whereas, F. Δt equation is known as impulse (**I**). Impulse is a constant force times multiplied by the time interval of the force acting on the mass. In reference to **F**.Δt = m.Δ**v** = Δ**p** equation, then impulse is a change in momentum of an object (Giancoli, 2005).

According to Newton's third law in Equation 5, if object A with a mass of m_1 delivers force to object B with a mass of m_2, then object B will exert a force on object A which is equal in mass but opposite in direction.

$$\boldsymbol{F}_{AB} = -\boldsymbol{F}_{BA} \tag{5}$$

by $F = m\mathbf{a}$ is in accordance with Newton's second law, hence we get the Equation 6.

$$m_1\boldsymbol{a}_1 = -(m_2\boldsymbol{a}_2) \tag{6}$$

by $a = \frac{\Delta v}{\Delta t}$, it is obtained that show in Equation 7 through Equation 9.

$$m_1\frac{\Delta\mathbf{v}_1}{\Delta t} = -\left(m_2\frac{\Delta\mathbf{v}_2}{\Delta t}\right) \tag{7}$$

$$m_1\Delta\mathbf{v}_1 = -\left(m_2\Delta\mathbf{v}_2\right) \tag{8}$$

$$m_1\Delta\boldsymbol{v}_1 + m_2\Delta\boldsymbol{v}_2 = m_1\Delta\boldsymbol{v}'_1 + m_2\Delta\boldsymbol{v}'_2 \tag{9}$$

$m_1\mathbf{v}_1 + m_2\mathbf{v}_2 = m_1\mathbf{v}_1' + m_2\mathbf{v}_2'$ equation is the law of conservation of momentum which states that "when a system does not receive an external force, the momentum of the system is always constant which the momentum of the system before the collision is the same as the momentum of the system after the collision" (Halliday et al., 2013).

Momentum and impulse are related with collision. According to the law of conservation of mechanical, collision has three types (Tipler & Mosca, 2010), namely 1) perfectly elastic collisions, 2) partially elastic collisions, and completely inelastic collisions.

Perfectly elastic collision occurs on two objects whose kinetic energy is conserved. in a perfectly elastic collision, the law of conservation of momentum and the law of conservation of kinetic energy apply, thus the coefficient of restitution (*e*) is 1 as seen in Equation 10.

$$e = \frac{\left(\mathbf{v}'_1 - \mathbf{v}'_2\right)}{\mathbf{v}_1 - \mathbf{v}_2} = 1 \qquad (10)$$

In a partially elastic collision, it applies only the law of conservation of momentum, while the law of conservation of kinetic energy does not apply. The value of the coefficient of restitution (*e*) in a partially elastic collision is $0 < e < 1$. A completely inelastic collision occurs if the velocities of the two objects after the collision are the same, that is $\mathbf{v}'_1 = \mathbf{v}'_2 = \mathbf{v}$. The value of the coefficient of restitution (*e*) in completely inelastic collisions is zero.

In the event of a collision, when the force acting on the object is described as a function of time, an impulse graph will be obtained as shown in the following Figure 2. Impulsive force graph.. The graph depicts the impulse force of object acting in a short time interval. The impulsive force starts at zero at t_1, then increases in value rapidly and passes through the peak until it drops back to zero at t_2 (Fowles & Cassiday, 2005).

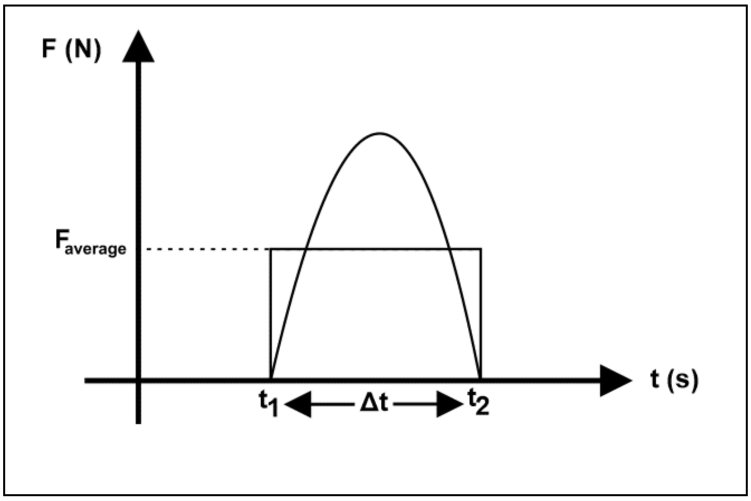

Figure 2. Impulsive force graph.

Specific Views

The tools and materials required for the research activities are two toy cars, adhesives, scale and smartphones with physics toolbox application installed (https://www.vieyrasoftware.net/) or phypox (https://phyphox.org/download/) which can be downloaded for free. Furthermore, the smartphone was attached to each toy car. In this research, the first toy cars and the smartphone's mass (m1) are 0.31345 kg, the second toy cars and the smartphone's mass (m2) are 0.32116 kg. Both cars were placed on a parallel line as shown in Figure 1.

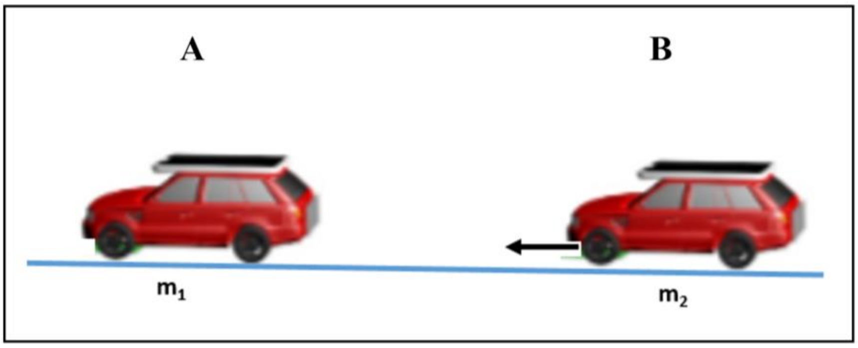

Figure 3. Experiment Order

The first car (m1) is idle, and the second car (m2) had been pushed forward toward the first car (m1) direction so that a collision occurred. While the second car set into motion, accelerometer sensor was turned on to record the data of acceleration (a) vs time (t). Accelerometer is turned off if both toy cars are no longer in motion. The data recorded in smartphone then exported to excel file. Furthermore, the data of acceleration (a) vs time (t) were analyzed using Newton's second law (Equation 1).

Analysis on Results of the Application of Concept of Momentum and Impulse in the Collision of Two Cars

Two cars colliding are examples of events related to the concepts of momentum and impulse. Data from the smartphone application on the collision of two cars using accelerometer sensor produced acceleration versus time as shown in Figure 4 **a** vs t graph on Figure 4 depicts the magnitude of the acceleration of car A which in the initial condition is 0 m/s2 (toy car is idle). At the moment t_1 =1.237 seconds, car B exerted a contact force in a short time interval dt = 0.025 seconds, causing car A to get an impulse that caused car A to move. The maximum acceleration experienced by car A during a collision is **a** = 27.919 m/s2.

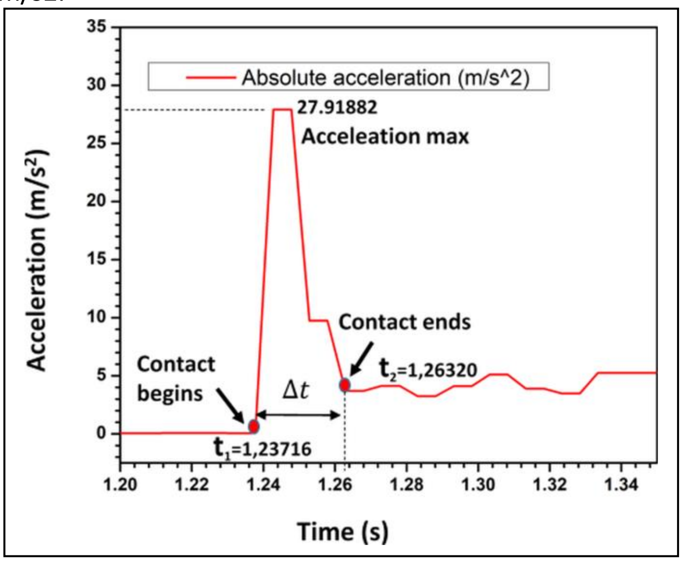

Figure 4. Toy car A acceleration measurement (m_1) collided by car B (m_2).

Toy car A in its idle state could move in motion because of the existence of force. The force received by car A is a contact force that acts in a short time interval that causes a change in speed. Total force acting in a certain time interval is called the impulse. impulse is the area under the curve **F** vs t (Colt & Sebe, 2019; Ganci & Lagomarsino Oneto, 2017). The magnitude of the impulse of car A when it was collided by car B is 0.1217 (n second), as shown in Figure 5. The magnitude of the impulse is equal to the change in momentum of car A when car B collide car A (match with the Equation 4), hence the velocity of car A after the collision is 0.427 m/second.

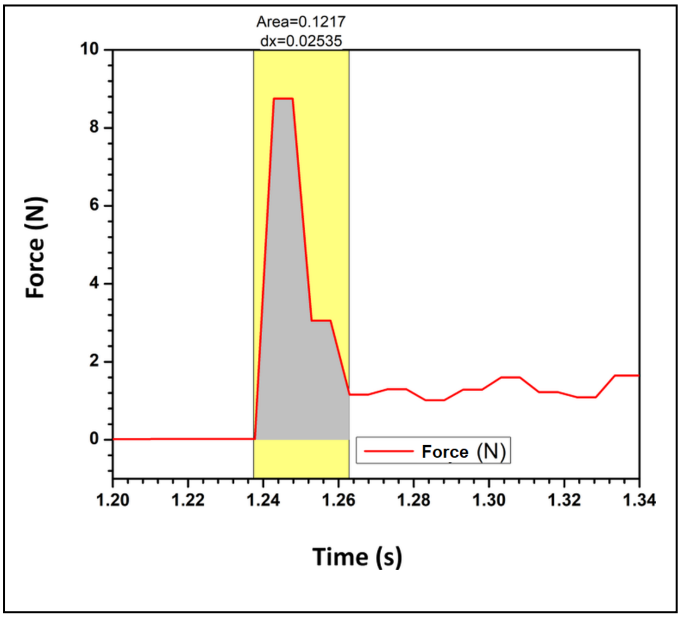

Figure 5. Car A impulse when it was collided by car B which is depicted as the area under the curve F versus *t*.

The contact force received by car A was brief, so it could be approximated by using the average force acting during the time interval *Δt*, as in Equation 4. The average force of 4.854 N in Figure 6 produces the same impulse as the actual time interval which is described as the area under the **F** graph vs t (Nuryadin & Hindawan, 2019).

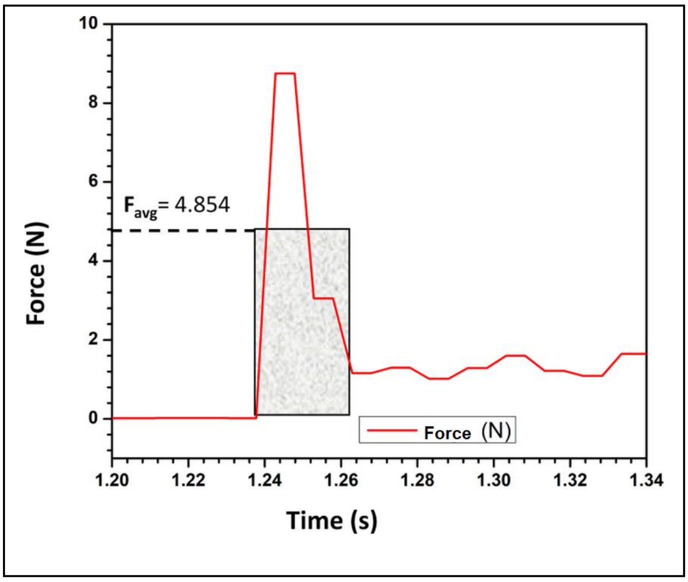

Figure 6. The average force acting on car A when it was collided by car B

Conclusion

The accelerometer sensor on a smartphone can be a mean to help students learning the essential concepts in momentum and impulse. From the acceleration versus time curve recorded by the accelerometer sensor, students can identify the acceleration and contact time when two objects collide, calculate the magnitude of the impulse, determine the change in momentum, calculate the velocity of the object after the collision and determine the average effective force (F_{avg}) that generates the impulse. This experiment apparatus made abstract concepts become more realistic and easier to identify with the help of accelerometer measurements on smartphones. Thus, teacher could design the experiment of momentum and impuls low cost and easily. In addition, this experiment can solve the obstacle of physics laboratory facilities in the schools.

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