Marbles and smartphone on physics laboratory: an investigation for finding coefficient of restitution

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Abstract. Experimenting is a basic skill that science students must have. Experimental activities are generally carried out in the laboratory. But by using a smartphone, many experiments can be done outside the laboratory. This research is an example of an experiment using a smartphone that can be carried out outside the laboratory. This study aims to measure the coefficient of marbles restitution through a simple experiment assisted by a smartphone. Marbles are dropped from a certain height, the Phyphox application on a smartphone will record experimental data through a sound sensor. Experimental data recorded through a smartphone is used to analyze the coefficient of restitution and mechanical energy of marble during a collision with the floor. The experimental results show that smartphones can be used to determine the coefficient of restitution and mechanical energy as an experimental tool. We hope that this experiment will be an alternative method for lecturers or physics teachers to demonstrate bouncing objects to determine the coefficient of restitution and mechanical energy loss.

1. Introduction
The collision between two interacting objects is one of the basic topics studied in physics at the secondary and undergraduate levels [3]. The topic of conservation of linear momentum coupled with the conservation of kinetic energy in perfectly elastic versus inelastic collisions are difficult concepts [15] for many students. When colliding both objects can lose or maintain their energy. Usually, we use the law of conservation of momentum and conservation of mechanical energy to explain this collision process. In two objects that experience perfectly elastic collisions apply both, while two objects that experience inelastic collisions apply only the law of conservation of momentum and do not apply the law of conservation of energy. But the collision can also be explained by the coefficient of restitution. The coefficient of restitution is expressed as the ratio of the relative speed of two objects before and after collision [1,6].

Collisions can be distinguished by the mechanical energy that the object maintains after the collision [15]. The value of the coefficient of restitution is between 0 and 1. The coefficient of restitution equal to 1 is described as a perfectly elastic collision. The total kinetic energy of the object remains constant during the collision, meaning that no energy is lost during the collision [15]. For example, if we drop
the ball vertically, then the ball will return to its original position [8]. The value of the coefficient of restitution equal to 0 is described as a perfectly inelastic collision [15]. Inelastic collisions occur at all if the end result of the collision process makes the object in a state of attachment so that both objects can be considered as one object and both move at the same speed or if we drop objects to the floor, then the object will not bounce. Energy kinetic objects completely disappear when collisions occur is not elastic at all, kinetic energy has changed into other forms such as sound, shape changes, heat and so on [15]. If the coefficient of restitution is in the range 0 < e < 1, the collision that occurs is partially inelastic.

Currently, smartphones are very close to human life, especially school-age teenagers. Besides having a lot of negative effects for students, for example, spending time playing games or chatting in the class [2], the use of this smartphone also has great benefits, especially for learning. No exception to learning physics. Smartphones play an especially important role in supporting physics experiments. A smartphone is a tool that is suitable for physics experiment activities because it is equipped with a number of sensors [2]. Most physics experiments can be done using a smartphone. In addition, this device provides a major contribution in increasing interest, motivation, learning outcomes, and student critical thinking [2,6,9].

Much research has been done to determine the coefficient of restitution. For example, measuring the coefficient of restitution for different materials using the ball as a material for discussion in teaching activities [4,6,10-13]. While in the use of smartphones, previous studies have reported measurements of the coefficient of restitution, such as using digital camera sensors by recording the motion of objects [4,7] but to get maximum results one must use a camera that has a high resolution which is quite expensive. In addition to using a video camera, measurement of the coefficient of restitution has also been carried out using a sound sensor on a smartphone to record the time interval needed between the first bounce to the next bounce [5], and research using a smartphone by measuring angular velocity and time-lapse during the collision process [3].

In this study, we determined the coefficient of restitution and mechanical energy using a smartphone equipped with a sound sensor and to analyze the relationship between the coefficient of restitution and the loss of mechanical energy. The software we use is Phyphox. This application is able to automatically record time intervals, height, and energy kinetic percentages of objects based on the sound of a marble impact on the floor, the results of this application recording are displayed immediately after the collision experiment is complete. The presence of this application is very easy for teachers and students because it becomes simpler and easier to understand how to use it.

2. Theoretical background

During this time, students are familiar with the definition of the coefficient of restitution as the ratio of the relative speed of two objects before and after the collision. But actually there are many ways to find the coefficient of restitution of objects, in addition to the relative speed can also be found by comparing the height, mechanical energy and even using angular velocity. In this study, we used height to find the coefficient of restitution. The height of the object is measured using a smartphone as a solution to the problem so far in collision experiments, namely the accuracy of the height data of the object after the collision which is measured manually using a ruler.

If we drop an object from a certain height to the floor, we can relate energy loss to how objects move before and after the collision. After touching the floor, the ball bounces back up to a certain height and again touches the floor next cycle within a certain time interval. If we assume that what is happening is partially inelastic collisions, then the height of the object bounces after collision with the floor decreases due to a portion of kinetic energy that has been converted to another form during the bouncing process. the coefficient of restitution can be determined from the square root of the height ratio before and after the collision [4]. We can write:

\[ e = \sqrt{\frac{h_{after}}{h_{before}}} \]  

Where \( e \) is the coefficient of restitution and \( h \) is the height.
In the event of a partially inelastic collision, the restitution coefficient value is in the range of $0 < \epsilon < 1$. This means that there has been a loss of mechanical energy during the collision. Mechanical energy loss can be analyzed using the following equation:

$$\Delta E = E_{after} - E_{before}$$  \hspace{1cm} (2)

When it reaches the highest peak, mechanical energy is equal to potential energy \([14]\), thus equation (2) can be written:

$$\Delta E = EP_{after} - EP_{before}$$

Because $EP = mgh$, the mechanical energy of the lost object is:

$$\Delta E = mg(h_{after} - h_{before})$$  \hspace{1cm} (3)

So it can be concluded that the loss of mechanical energy of objects that collides vertically with immovable objects (stationary) is equal to the difference in the potential energy of the object when it reaches its maximum height.

3. Experimental setup
Experimental setup to determine the coefficient of restitution of marbles is enough to use simple equipment. The tools needed include marbles, digital balance sheets, and smartphones. The illustration of experiments can be seen in Figure 1. In this study, we used an Android smartphone OPPO F5 type. While the application that we use is Phyphox version 1.1.3, it can be downloaded for free at Playstore or App Store.

After all the tools have been prepared, the next step is to conduct experiments to retrieve experimental data. Then the sound sensor on the smartphone is activated and the marbles are dropped from a certain height with free-fall motion (without initial speed). When marbles hit the floor the sound sensor on the smartphone works and the application records the height, times, and kinetic energy of the marbles. The sensor on the smartphone starts working for a moment when the sound produced by the collision between the marble and the floor occurs then stops colliding next along with the second data starting the next onwards until the smartphone records for five collisions. After the collisions are complete, the smartphone sensor is turned off and the data recorded on the smartphone is stored for analysis. Arrange the smartphone as close as possible to where the marbles fall so that data can be recorded perfectly.

4. Results and Discussion
Figure 2 shows experimental data of marbles dropped to the floor and then bounced in five times. Times and height (figure A) and the percentage of remaining energy (figure B) recorded through the sound sensor on the smartphone simultaneously. Then based on these data will be analyzed to determine the coefficient of restitution and mechanical energy of marbles and the relationship between the coefficient of restitution and the loss of mechanical energy.
Data obtained from a smartphone is then analyzed to determine the coefficient of marble restitution. The results of the analysis can be seen in table 1. Based on table 1, we found an average value of the coefficient of restitution of 0.9260. The value of coefficient of restitution found indicates that the collision that occurred was a partially inelastic collision [15].

Previously we found the marbles restitution coefficient was 0.9260. According to the results of the experiment, the height of the marbles decreases with each collision, but what about the reduction in the height of the marbles. Therefore, we analyzed the mechanical energy of the marbles during the collision. The height of the marbles is decreasing as the number of mechanical energy decreases.

**Figure 2.** The experimental data of height and times (A) and energy (B) recorded from smartphone.

| Times (s) | Speed (ms\(^{-1}\)) | e   |
|-----------|----------------------|-----|
| 1.023     | 5.018                |     |
| 0.947     | 4.645                | 0.9257|
| 0.884     | 4.336                | 0.9335|
| 0.821     | 4.027                | 0.9287|
| 0.752     | 3.689                | 0.9160|
| **Average** | **3.689**         | **0.9260** |

Based on Figure 2, the mechanical energy of the marbles is displayed as a percentage, so it is not yet known how much actual mechanical energy is stored on the marbles before and after the collision. We, therefore, analyzed the mechanical energy of marbles using the equation of potential energy \( E_P = mgh \), in which the mechanical energy of marbles was calculated based on the maximum height reached by the marble each time after colliding with the floor. Theoretically, when it reaches its maximum height, its mechanical energy is equal to potential energy, because the velocity of the marble is equal to 0 when it reaches its highest point so that all of its kinetic energy turns into potential energy [14].

The loss of mechanical energy of objects that collides vertically with immovable objects is equal to the difference in the potential energy of the object when it reaches its maximum height. Thus, equation 3 can be used to calculate the mechanical energy of marbles. But before it, we have weighed the mass of the marbles and determined the value of the acceleration due to gravity. The mass of marbles in this experiment is 5.33 grams and the value of \( g \) is 9.81 ms\(^{-2}\), according to the gravitational acceleration of objects around the earth's surface.

Table 2 is the mechanical energy of marbles during the collision. The mechanical energy of marbles is analyzed based on the height of the marble during the collision recorded by the smartphone. Based on table 2 we find that the mechanical energy of the marbles is disappearing every collision with the floor which affects the height of the marbles after the collision. Periodic loss of mechanical energy causes the height of the marbles to be reduced.

Total mechanical energy does indeed remain constant when the ball is in the air, however, mechanical energy is lost during each bounce [14], some of the energy changes to other forms, one of the changes
we can observe are the change in sound shape. To make it easier to see the decrease in height of each marble and collide and analyze the loss of mechanical energy, we will present it in Figure 3.

Table 2. The Mechanical Energy of Marbles During Collisions

| h (m) | E (Joule) | ΔE (Joule) |
|-------|-----------|------------|
| 1.2828 | 0.067      |            |
| 1.1001 | 0.057      | -0.010     |
| 0.9584 | 0.050      | -0.007     |
| 0.8268 | 0.043      | -0.007     |
| 0.6942 | 0.036      | -0.007     |

Figure 3. The Mechanical Energy of Marbles During Collisions

Based on Figure 3 it is observed that the amount of mechanical energy of marbles decreases every time a collision occurs as can also be seen in table 3. The negative sign in table 3 shows that the amount of mechanical energy of marbles is lost during a collision. The coefficient of restitution of marbles is 0.9260, in the range of 0 < e < 1, meaning that the collision is partially inelastic. In partially inelastic collisions, the kinetic energy of objects decreases constantly after the collision because some energy is dissipated during the collision process as shown in Figure 3

5. Conclusion
We have demonstrated the measurement of the coefficient of restitution and mechanical energy for marbles using a smartphone sensor. The height of the marbles that bounces off the floor before and after the collision is measured using the sound sensor found in the software. Data were analyzed to determine the coefficient of restitution and the amount of mechanical energy loss during the collision. Values coefficient of restitution obtained from height can be found constantly and in accordance with mechanical energy loss of marbles. It can be concluded that it is possible to determine the coefficient of restitution and the amount of mechanical energy of objects by using a smartphone as an experimental tool. We have also analyzed the mechanical energy stored in marbles during collisions, as well as the constant loss of mechanical energy during collisions. We hope that this method will be useful for physics teachers to demonstrate bounce objects to determine the coefficient of restitution and mechanical energy. This method is easy to do, but what needs to be paid attention is when dropping the marble you have to be as close as possible to the smartphone so that the sound sensor of the smartphone works optimally. If the marble falls far from the smartphone, the smartphone recording result will be less accurate.

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