Demonstration of a new collision phenomenon using air track

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Abstract. The touching collision between two objects on the air track still allows a change in the total kinetic energy. In this work, the air track props has been successfully modified to demonstrate the collision without touching between two objects. The modification was done by adding thin cylindrical magnets to the two objects of air track set. This props demonstrates a very different Physics phenomenon from the collision between two objects touching each other. Analysis of total momentum of the two objects before and after collision show that the law of conservation of linear momentum is applied. The collision without touching between two objects produce an elastic collision and its coefficient of restitution $e=0.99$. The props of collision without touching was validated by the experts on physical aspect and pedagogical-concept. Based on the props physical aspect validation obtained a percentage of 95.6%. Based on the props pedagogical and conceptual aspect validation obtained a percentage of 91.6%. Besides, the results of the trial based on students responses got a percentage 90.65%. So, it can be concluded that the props of collision without touching is highly valid to be used as collision teaching props in class. The results of the development of this props are expected to provide a more comprehensive understanding and avoid students misconceptions for the collision material.

1. Introduction

Props have a very important role as a supporting tool in learning activities. Various Physics phenomena can be presented or illustrated in real terms using props [1,2]. Abstract Physics phenomena such as electric field lines, light diffraction, nanometer-scale structures such as atoms and crystals, to a very large solar systems, etc. can be illustrated in props [3-5]. Direct observation of Physics phenomena from props has a very significant impact on increasing students’ conceptual understanding [6]. This understanding is formed from a process of observing the way scientists acquire knowledge.

The development of props in Physics learning has been produced for a variety of Physics materials [7-9]. The main aspect used as the basis for the development of props is the suitability of phenomena and concepts. However, the development of props is often damaged by the Physics concept with ideal systems point of view such as the phenomenon of elastic collision. This type of collision is classified in a very ideal condition which the total kinetic energy of the objects are same before and after the collision [10]. Various forms of textbooks that are used as learning resources and learning activities always illustrate elastic collision that occur in collision on billiard balls. However, the collision of the two billiard balls still occurs by physical contact or touch each other.

Nowadays, collision props have been developed with the support of sensor and electronic devices such as air track collision props [11]. The touching collision between two objects on the air track still
allows a change in the total kinetic energy. In this work, the development of collision props is done by modifying the air track props to illustrate elastic collision in real terms with a new mechanism. Air track props was developed to produce collision without touching.

2. Methods
This development or R & D research develops air track props for collision without touching. R & D is a process for developing and validating a product [12,13]. The development of props was done by modifying the air track objects by adding thin cylindrical magnets. In addition, a guide book to the use of props is prepared to complement the props develop, so it can support learning by using the props.

This study, both development and trial test, was carried out in the Fundamental Physics Laboratory, Universitas Negeri Semarang. The research and development of air track props for collision without touching consist of six stages adapted from Borg and Gall [14]. The development research phase includes: 1) Analysis of potential and problem, 2) product design, 3) design validation and design revision, 4) product testing, 5) analysis of trial results, and 6) final product assembly. The trial was conducted only in small scale trials to determine the ease of use of the props based on students’ responses. The trial respondents consisted of twenty students whose members of the Fundamental Physics Laboratory Assistant Group 2019/2020. The instrument used consisted of a validation sheet to measure the validity and a response questionnaire to measure the practicality.

3. Results and Analysis
The results of the development of this study is the modification of air track props to demonstrates a very different physical phenomenon from the collision between two objects touching each other. The development of props is carried out based on Newton’s Third Law understanding. Application of Newton’s Third Law understanding in terms of force interactions in the form of magnetic dipole interactions or electrostatic force interactions [15,16].

Collision is illustrated by two models, a contact collision and a collision using a spring. Start two trucks moving towards each other on a “frictionless” model railroad. They keep constant velocities until they hit with a smack; then after very brief contact they rebound with different velocities, but the same total momentum. Now equip the trucks with buffers of good steel springs. The collision takes longer. The final rebounding velocities may be greater than those after an abrupt smack, but momentum is conserved. At very intermediate stage during the collision, momentum is conserved: the total momentum of the two trucks is equal to their total momentum before the collision started. In the middle of the collision, when they are closest and have compressed the springs most, the two trucks and springs are all moving together with one velocity. In each type of collision (springs pushing or smack of contact) equal and opposite forces develop, at some stage of the approach, that push the colliding bodies outward and go on pushing until they are apart again [17].

The air props were developed by adding thin cylindrical neodymium magnets to the two objects of air track set. Magnets in the front of each colliding objects are mounted with similar poles facing each other, so that if the two objects collide, they will repel each other. The addition of magnetic components represents a very different Physics phenomenon related to the conservation of linear momentum of a collision as shown in Figure 1.
Figure 1. Illustration of a new collision phenomenon using air track.

The two objects, object 1 with mass \( m_1 \) travels at a velocity of \( v_1 \) on the air track because it is pushed, while object 2 with mass \( m_2 \) is placed between the two light gates. The initial velocity of object 2 (\( v_2 \)) is equal to zero because the object is at rest. When object 1 passes through the light gate 1, the initial velocity of the object can be read directly on the timer counter. After object 1 collides object 2, object 1 is in a rest so that the final velocity of object 1 (\( v_1' \)) is equal to zero, while object 2 moves backward at a velocity of \( v_2' \) which can be measured by the light gate 2. The initial experiment was carried out by taking data. The results of the object velocity measurement before and after the collision are shown in Table 1.

Table 1. Air track objects velocities before and after collision.

| Experiment | \( m_1 \) (kg) | \( m_2 \) (kg) | \( v_1 \) (m/s) | \( v_2 \) (m/s) | \( v_1' \) (m/s) | \( v_2' \) (m/s) |
|------------|----------------|----------------|----------------|----------------|----------------|----------------|
| 1          | 0.2251         | 0.2249         | 0.4748         | 0              | 0              | 0.4704         |
| 2          | 0.5532         |                | 0.5327         | 0              | 0              | 0.5387         |
| 3          |                | 0.2249         | 0.3129         | 0              | 0              | 0.3056         |
| 4          |                | 0.2249         | 0.5277         | 0              | 0              | 0.5202         |
| 5          |                | 0.2249         | 0.5361         | 0              | 0              | 0.5283         |
| 6          |                | 0.2249         | 0.5401         | 0              | 0              | 0.5376         |

Furthermore, Table 1 data is analyzed so as to produce linear momentum before the collision \( (p) \) and linear momentum after the collision \( (p') \) as shown in Table 2.

Table 2. Linear momentum of the system before and after the collision.

| Experiment | \( p \) (kg.m/s) | \( p' \) (kg.m/s) |
|------------|-----------------|-----------------|
| 1          | 0.1069          | 0.1058          |
| 2          | 0.1245          | 0.1212          |
| 3          | 0.0704          | 0.0687          |
Based on the data analysis conducted, it can be concluded that the repulsive force between similar magnetic poles can produce the same momentum. It can be seen in the calculation results in Table 2 which shows the amount of linear momentum of the system before the collision \( p \) is equal to the linear momentum of the system after the collision \( p' \), although the collision of the two objects did not occur in physical contact or touch each other, but through an intermediary repulsive force between two similar magnetic poles. The linear momentum of the system before the collision \( p \) is equal to the linear momentum of the system after the collision \( p' \), so the law of conservation of linear momentum of the system is applied. The two objects form an isolated system, so the law of conservation of linear momentum of the system is applied. Momentum in both states is equal also means that kinetic energy does not lost and change in the form of other energies, such as sound.

The type of collision in the experiment that was carried out was an elastic collision. The type of collision also can be known by calculating coefficient of restitution \( e \). The coefficient of restitution \( e \) of each initial experimental data using props are shown in Table 3.

**Table 3. Coefficient of restitution.**

| Experiment | \( e \)  |
|------------|--------|
| 1          | 0.9906 |
| 2          | 0.9738 |
| 3          | 0.9768 |
| 4          | 0.9859 |
| 5          | 0.9854 |
| 6          | 0.9954 |

The result of coefficient of restitution \( e \) calculation in Table 3 is equal to 0.9.. said to be approach to 1. This is done by ignoring the difference in very small values for the purposes of making conclusions, so that 0.9.. can be considered 1. Collision with this value is an elastic collision type. Therefore, based on the results of coefficient of restitution \( e \) calculation that have been carried out, it can be concluded that the type of collision in the initial experiment using props was an elastic collision.

After the initial product is finished, the next step is to test the validity of the expert consisting of physical aspect and pedagogical-concept. The experts were also conducted product judgement based on the results data of initial experiment using props. Based on the props physical aspect validation obtained a percentage of 95.6% with highly valid criteria. Based on the props pedagogical and conceptual aspect validation obtained a percentage of 91.6% with highly valid criteria.

The trial product for twenty students was conducted to determine the ease of use of the props and its guide book in general for their use. Students gave responses to the props after using the props. Students’ responses were obtained from a questionnaire that had been compiled. The results of the trial based on students’ responses got a percentage 90.65% with a very high criterion.

4. Conclusion

This product was produced in the form of development air track props for collision without touching. The development was done by adding thin cylindrical magnets to the two objects of air track set. Based on the props physical aspect validation obtained a percentage of 95.6%. Based on the props pedagogical and conceptual aspect validation obtained a percentage of 91.6%. Besides, the results of the trial based on students responses got a percentage 90.65%. Therefore, the props of collision without touching is highly valid to be used as collision teaching props in class. The results of the development of this props
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