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The Design of One-Dimensional Motion and Two-Dimensional Motion Learning Media Using Digital Camera and Tracker-Based Air Track

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Abstract

This research describes the results of the development of 2D air track tools designed for one and two-dimensional motion experiments with small frictional forces. Friction is minimized by using wind gusts through small holes made in all parts of the runway. Motion detection devices used are digital cameras and trackers. Digital cameras are used to record the motion of objects on a platform in the form of video with a specific frame-rate. Tracker is used to analyzing videos that contain information about object motion. This tool has been tested on one-dimensional motion, that is, an object that slides over an inclined plane and two-dimensional motion in the case of a collision of two objects. In the case of one-dimensional position graphs against time can be displayed, the instantaneous velocity and average and acceleration can be accurately determined. In the case of the collision of two objects, the position graph against time can also be displayed for each object before and after the collision. The velocity vector can be determined accurately so that the law of conservation of momentum and kinetic energy can be verified. One and two-dimensional motion are the concepts that underlie almost all other concepts in physics. Therefore one and two-dimensional motion experiments are important to build students' experiences of the concept. Thus 2D air track platform based on digital cameras and Tracker software can be used as a physics learning media on motion kinematics materials that can display various kinematics graphs so that information about motion is complete.

Keywords: video analysis, tracker, two-dimensional collision, acceleration due to gravity

INTRODUCTION

In physics learning, knowledge transfer not only happens through the learning of theories and concepts but also through experimentation. Through experimental activities, students' understanding of the concepts of physics will improve because they find those concepts by themselves from direct experience (Pattar, Raybangkar, & Garg 2012). Experimental activities can motivate students and open their minds to understanding physics materials (Besson et al. 2007; Rodríguez & Albeni 2017). Well planned and well-conducted experiments can produce high-quality learning. Therefore, educators' creativities are needed in developing experimental tools according to the concepts of physics that will be taught (Haris & Lizelwati 2017).

It is important that the transformation of knowledge via media must consider students' thinking level. The making of instructional media needs to meet media eligibility criteria. Those criteria include: (1) learning media must be following the concepts of physics, (2) learning media must be following the existing curriculum, (3) forms of learning media must be attractive and in line with research subjects, (4) learning media must be easily understood, and (5) learning media must be easy to use (Afriyanto 2015). Learning media ought to be a place for learning for students. Learning media should be the learning resources for students that can encourage critical thinking and higher-order thinking. Higher-order thinking skills must be developed in learning. Thinking skill is an important component in the development of knowledge and needed by students in dealing with problems in the learning process (Mahanal & Zubaidah 2017).

In stimulating students to think critically, there are so many experiments about motion material that can be developed from daily life situations. The examples of one- and two-dimensional motions are marbles sliding on a slope, the motion of a falling object, collision on billiard balls, car accidents, and carom colliding coins. Those motion examples can be reviewed from whether there is a friction of the motion. Students' visualization about motion cannot be easily made because it is difficult for the students to observe directly small friction of a motion (Eager, Pendrill & Reistad 2016). Students' ability to solve problems in the concept of motion kinematics is still low (Mustofa & Rusdiana 2016). It is necessary to have a system to detect motion so that students can quickly learn about the motion of a system that only has small friction. Students must be directly involved in learning (Serevina & Muliyati 2015). The daily experience needs to be formalized in a controlled experiment to introduce the concepts of speed and acceleration to students by detecting one-dimensional motion and two-dimensional motion. Learning must be designed to practice the ability of students to develop their thinking skills (Marieta, Rusnayati & Wijaya 2016)

The development and use of technology are very important in the field of education to support the need for learning in introducing concepts about motion (Paraskeva, Bouta & Papagianni 2008). Digital cameras can be used to record the motion of an object in the form of video at a specific frame rate (Vera, Rivera & Fuentes 2013). Tracker software can be used to analyze videos containing information about the motion of an object. The tracker software supports the need for data accuracy (Hockicko, Krišťák & Němec 2015) so that difficulties encountered by students in learning motion can be solved quickly (Hockicko, Krišťák & Němec 2015; Hockicko, Trpišová & Ondruš, 2014; Kalajian 2013). The use of this software can overcome some of the students' misconceptions about the motion by connecting abstract-physical concepts into real-life through video analysis. This is an innovative and effective way to learn one-dimensional motion and two-dimensional motion (Wee et al. 2012). The use of analytical video-based learning media in the learning process is not only interesting for students, but it also can provide more information for students (Rodríguez & Alberú 2017).

This study aims to develop an experiment tool of tracker and digital camera-based 2D air track in a one-dimensional motion experiment, i.e., a sliding object on an inclined plane and a two-dimensional motion experiment, i.e., the collision of two objects. The development of this experimental tool is expected to help and facilitate teachers in delivering more interesting, non-monotonous subject matter, helping students understand the most basic physical concepts of motion in Newton's II law theory, the law of conservation of momentum and kinetic energy, and students can conduct experiments live or through video (Pili & Violanda 2019).

METHODS

The study began by designing a 2D air track, building experimental sets of testing tools, and finally analyzing the results of experiments. In the first step, a 2D air track tool design was made using the Corel draw software, as shown in FIGURE 1. An acrylic laser cutting machine was used to print the design to make sure that the resulting design is neat and precise. At the four sides of the air track, a 1 cm height barrier was created to prevent the sliding object glides out of the air track. Objects that were used in experiments are made of circular acrylic.

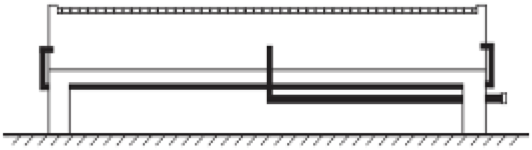
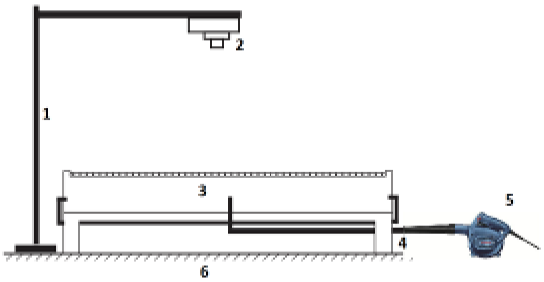


FIGURE 1. The 2D Air Track Design

The second step was testing the tool. The air track was connected to a compressor with a discharge capacity of 4.5 m^3 per minute. A camera was mounted on a tripod placed at the middle position of the air track. The camera was calibrated according to the path of the air track field so that data from the video recording matched the actual size. The camera used for this experiment is a DSLR-type camera with a speed of 50 fps (frames per second), meaning that in one second, the camera can capture 50 different images. The time interval between frames is 1/50 seconds (Hockicko, Krišťák & Němec 2015). The camera frame rate affects the number and quality of images converted from the video (Ayop 2017; Wantoro, Sudjito, & Rondonuw 2016). The higher of fps number, the smoother of the moving image. The scheme of tool installation for the experiment can be seen in FIGURE 2.



Information:
(1) Tripod
(2) Camera
(3) 2D air track
(4) Hole of wind blower
(5) Compressor
(6) Floor

FIGURE 2. The schematic for tool installation.

In the third stage, data analysis of the results of the experiment and testing of the tool was made using Tracker software. The tracker software was used to determine the motion of an object on each frame and provide a graphical analysis of the experimental video (Chanpichai & Wattanakasiwich 2010; Wantoro, Sudjito, & Rondonuw 2016). The length of the calibration tool is 0.5 m according to the length of the air track, and the time interval is 1/50 seconds according to the camera frame rate. Thus, the instantaneous speed can be determined by measuring the distance between points/holes divided by the time interval. The tracking results were presented in the form of a graph describing the relationship between the object's position and time. To match the data and curves, plotting of data points was made and a line was drawn according to the obtained data. To get the line equation that matches the data, a parabolic fitting curve (quadratic function) on the Data Tool Tracker was selected. This quadratic function is stated, as shown in EQUATION (1).

$$s = At^2 + Bt + C \tag{1}$$

Where the variable s is the object's position (m), A is the object's acceleration (m/s^2), B is the object's initial speed (m/s), and C is the object's initial position (m).

RESULT AND DISCUSSION

Design of the Tool

The 2D air track device was designed using acrylic material with 5 mm thickness. The size of the inner platform is l: 50 cm, w: 50 cm, and h: 6 cm. On the surface of the air track, a matrix was made for 2401 holes with 1 cm distance of the gap between holes and diameter of each hole was made as small as possible with 1 mm size to create a strong push force of the coming out wind for the object on the runway as shown in FIGURE 3.

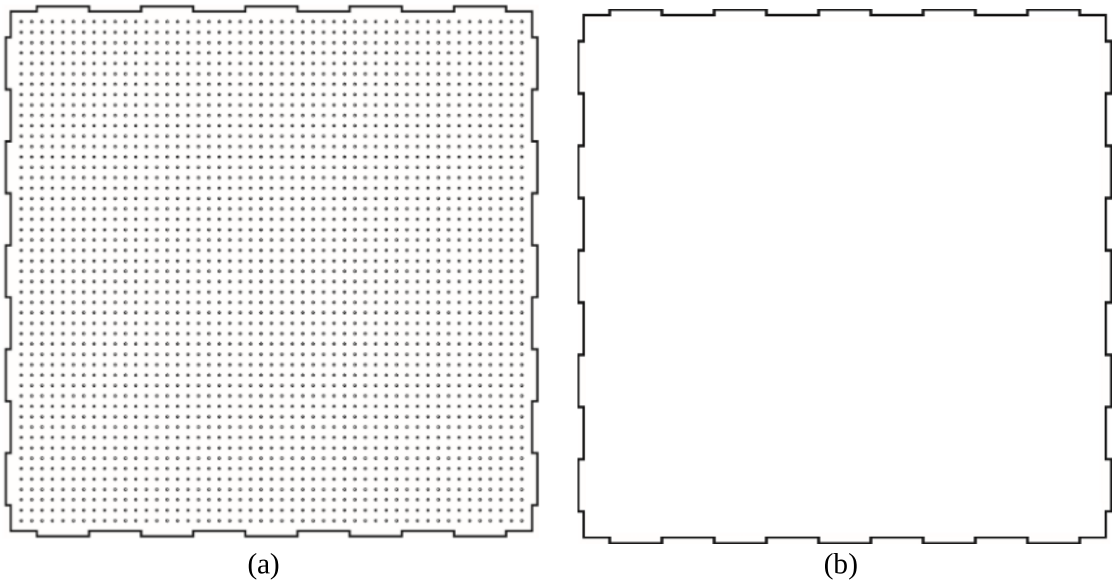


FIGURE 3. (a) Top view of the design (b) Bottom view of the design

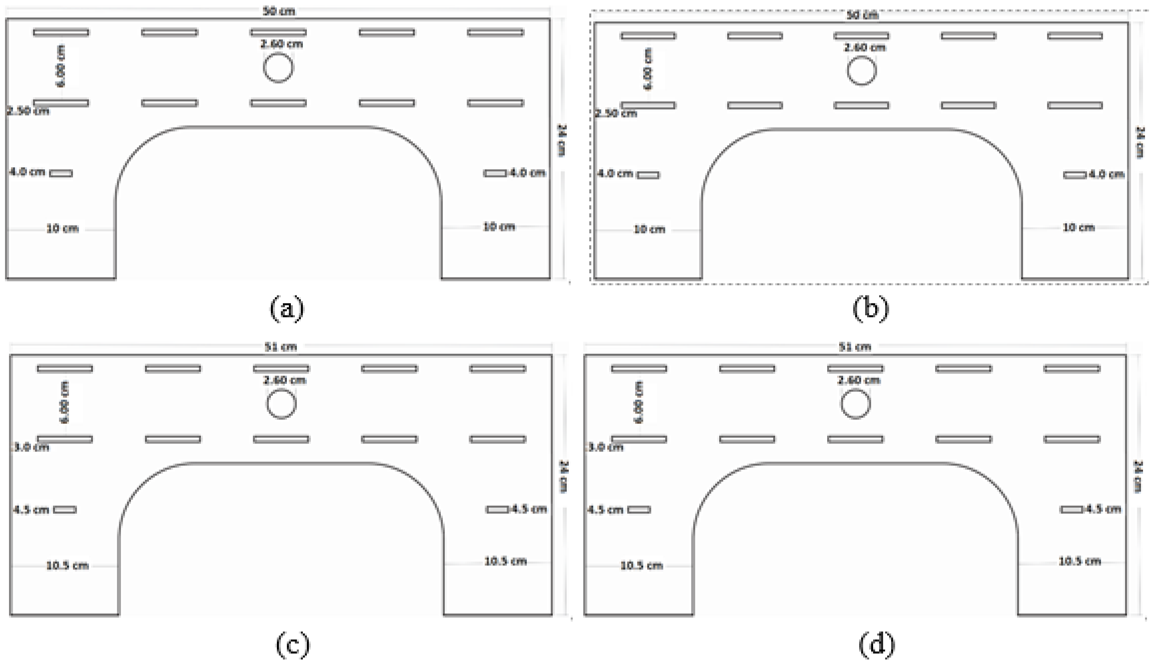


FIGURE 4. Side view of the design and supporting pad.

FIGURE 4 (a) (b) (c) and (d) show the view of opposite sides of the design, which both sides have the same sizes. The sizes are adjusted to the 5 mm thickness of the acrylic. The height of the air track is 24 cm, measured from the surface to the supporting pad. Four holes of wind tunnels were made on the sides of the air track with two purposes: to evenly distribute the wind that enters the air track and to create a strong push force of the wind that comes out of holes matrix to push objects on the air track.

(a) (b)

FIGURE 5. (a) Top view of 2D air track, (b) Side view of 2D air track

The FIGURE 5 (a) shows that on all four sides of the air track, wind tunnels are made using a 0.75-inch diameter of PVC pipes and rubber bands are added at the outside and inside of tunnel openings so that the incoming wind will not come out from the sides of the air track. A hole with 1-inch diameter is made to connect the air track with a compressor at the bottom position, which is indicated by the letter X, as shown in FIGURE 5 (b). The air track is designed in such a way to minimize the friction force where objects can be moved along the x and y axes. This allows the foundation of the air track to be used for motion kinematics experiments Wantoro, Sudjito, & Rondonuw. 2016).

To find out whether the air track tool that has been designed could work well, the tool was tested. The test included testing of one-dimensional motion in the case of gravitational acceleration (g) on an inclined plane and two-dimensional motion in the case of collision of two objects.

The use of the tool in the case of gravity (g)

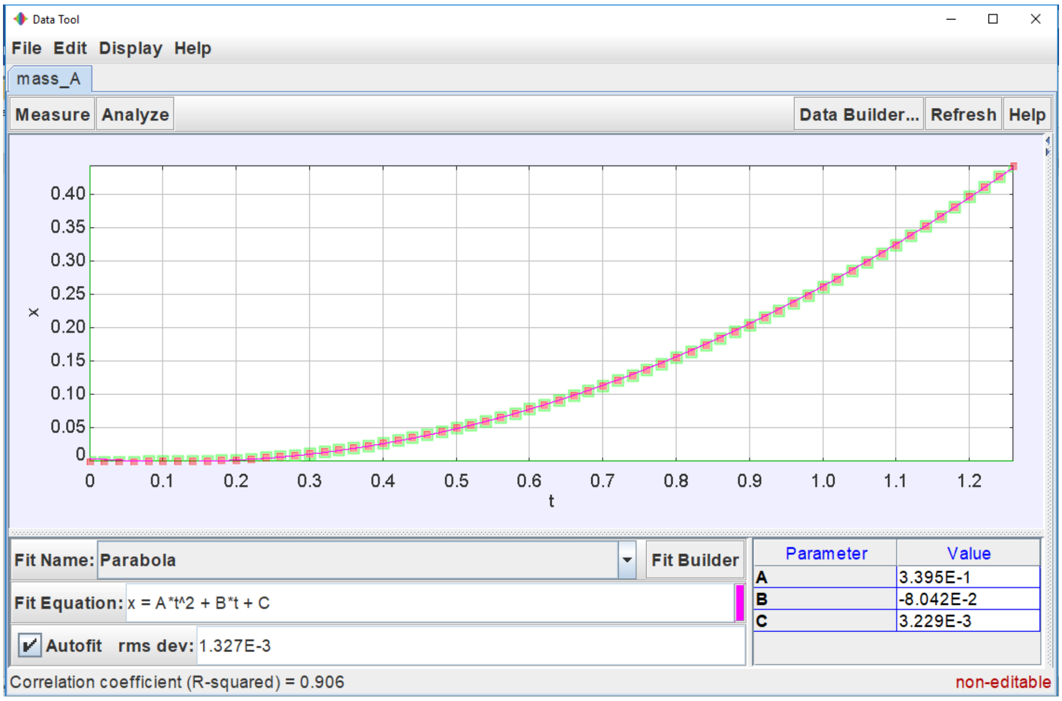


FIGURE 6. The Display of data tool of an object that moves linearly on a 0.5 m long inclined plane.

In determining the gravitational acceleration, four experiments were carried out with different masses of objects. FIGURE 6 shows the graph position related to time, where the object experiences an accelerated uniform linear motion. The object used for the experiment has a mass of 14.46 grams, 5.7 cm in diameter, and 5 mm thickness. The object slides at zero initial velocity and 4° of platform sloping angle (Li 2012). The object experiences an acceleration of 0.67 m/s^2 and gravitational acceleration of 9.57 m/s^2.

For objects with masses of 3.29 grams, 3.33 grams and 3.38 grams, with a diameter of 3.5 cm and a thickness of 3 mm, respectively, the acceleration of the objects were 0.68 m/s^2, 0.70 m/s^2, and 0.68 m/s^2, and the gravitational acceleration of the objects, respectively, 9.86 m/s^2, 10.14 m/s^2, and 9.86 m/s^2. The average value of gravitational acceleration from the experiment on an inclined platform was 9.86 m/s^2. Through the analysis of the experiment, it shows that the gravitational acceleration value (g) varied. This is due to the inaccurate tool calibration, and the influence of objects' color contrast that causes determination of the objects' point of mass becomes less precise, and in turn, this affects the results of the experimental video analysis (Suwanpayak et al. 2018).

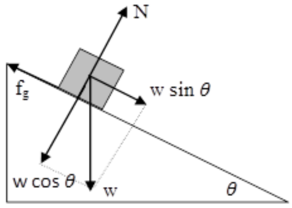


FIGURE 7. The acting forces on an inclined plane using Newton's 2nd law equation which the equation of gravitational acceleration is obtained as shown in EQUATION (2) (Halliday, D., Resnick, R., dan Walker, J., 2010).

$$g.\sin\theta = a \qquad (2)$$

Where, g = Gravitational acceleration (m/s^2)

θ = Platform sloping angle (^{0})

a = Object acceleration (m/s^2)

FIGURE 7 shows that the surface of the inclined platform is very slippery that results a zero friction ($f_g = 0$). The object moves due to the force of the wind coming out of the matrix of the platform tunnels with gravity parallel to the inclined platform.

In addition to determining the gravitational acceleration on an inclined platform, the gravitational acceleration is also measured using a simple pendulum. The results of the experiment, the average g is obtained of 9.77 m/s^2. The results of the experiments on the sloping platform and the simple pendulum show that the value of gravitational acceleration approaches the value of gravitational acceleration in the literature (Afifah et al. 2015). Generally, in physics learning, the value of gravitational acceleration has been determined at 9.8 m/s^2 without any verification. Based on this study, the value of gravitational acceleration (g) can be measured by various methods, i.e., by performing an experiment of motion of an object on an inclined platform and an experiment using a simple pendulum. The importance of the experiments carried out can help students to understand Newton's II Law and its application and this experimental tool is easy to use in the learning process (Cáceres & Martínez 2015; Pili and Violanda 2019).

Use of the tool in the case of two-dimensional collision

An experiment of the two-dimensional collision was performed using two objects which object A has a mass of 3.38 grams, and object B has a mass of 3.29 grams, and respectively, the object has 3 mm thickness and 3.5 cm diameter so that the objects can be supported by wind tunnels with a minimum of nine tunnels. The results of the video were analyzed using the Tracker software to determine the velocity before and after the collision. FIGURE 8 (a) - (f) shows the graphs of position versus time that describe the results of the data fitting.

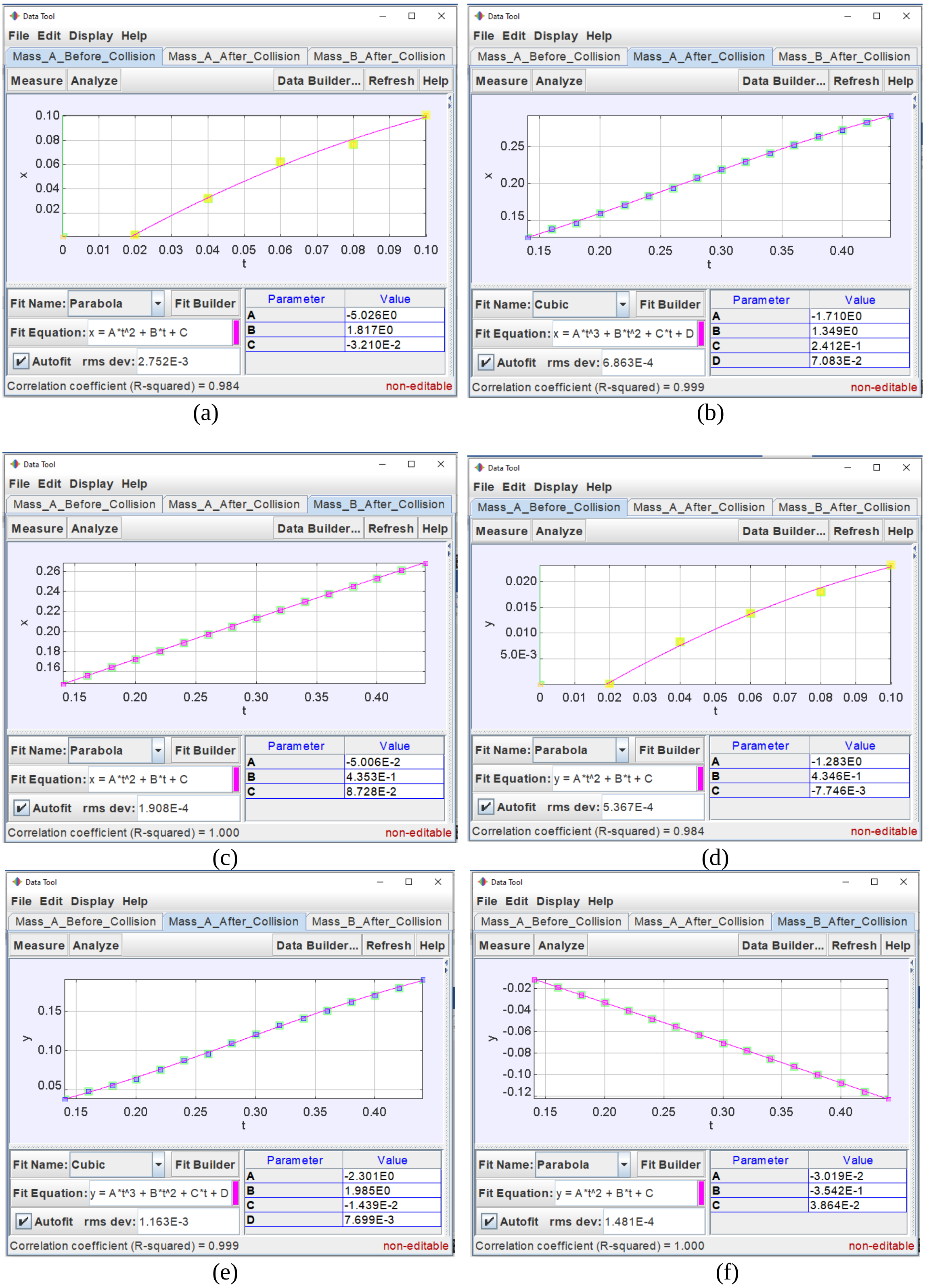


FIGURE 8. (a) The figure shows the Data Tool of position (x) to time (t) using EQUATION (1) which shows that $v_{A_x} = 0.81$ m/s and $a_{A_x} = -10.05$ m/s^2. (b). $v_{A_x} = 0.52$ m/s and $a_{A_x} = 1.26$ m/s^2. (c). $v_{B_x} = 0.42$ m/s and $a_{B_x} = -0.10$ m/s^2. (d). The figure also shows the Data Tool of position (y) to time (t), using EQUATION (1) which shows that $v_{A_y} = 0.18$ m/s and $a_{A_y} = -2.57$ m/s^2. (e). $v_{A_y} = 0.43$ m/s and $a_{A_y} = 2.32$ m/s^2. (f). $v_{B_y} = -0.36$ m/s and $a_{B_y} = -0.06$ m/s^2.

The FIGURE 8 (a), (c), (d) and (f) show that the object *A* before the collision and the object *B* after the collision experience a decelerated uniform linear motion. FIGURE 8 (b) and (e) show that the object

A after the collision experiences a non-uniform linear motion, where the object is first accelerated then decelerated. It is because the platform is placed on a frictionless floor; so that acceleration occurs due to gravity, then a deceleration occurs from the push of the wind coming out of the platform tunnel matrix. FIGURE 8 (f) shows that the instantaneous speed of object *B* after the collision shows a minus value because the object moves downward in the negative y-axis direction.

The collision event of object *A* that hits object *B* does not occur exactly at the center of object *B* mass so that the two objects from an angle after the collision. The object A creates an angle of 42.5 º and object B creates an angle of -42.5º toward the normal line. The existence of the concept of momentum conservation law can be investigated from the collision event. Theory the momentum before and after a collision is constant, as shown in EQUATION (3) (Halliday, Resnick and Walker 2010).

$$\sum \vec{p} = \sum \vec{p}\,' \tag{3}$$

where P = m.v, which m the mass of the object (kg) and v is the velocity of the object (m/s)

TABLE 1. Momentum before and after the collision

Position	X axis $\vec{p}\ (x10^{-3}\ Kg.m/s)$	Y axis $\vec{p}\ (x10^{-3}\ Kg.m/s)$
Before Collision	$\sum p_x$=2.7	$\sum p_y$=0.6
After Collision	$\sum p_x'$=2.3	$\sum p_y'$=0.2
	$\sum p_x > \sum p_x'$	$\sum p_y > \sum p_y'$

TABLE 1 shows the analysis of the validity of momentum conservation law, in which the amount of momentum can be analyzed based on vector quantities on the x and y axes (Wantoro et al. 2016). The total momentum before a collision is not the same as the total momentum after a collision, so the momentum value of the object did not meet the theory, such as shown in EQUATION (3). It is because the collision is not elastic.

The collision event is closely related to momentum and kinetic energy. Based on the theory, the law of conservation of kinetic energy states that the kinetic energy before a collision is the same as the kinetic energy after a collision, as shown in EQUATION (4) (Halliday et al. 2010).

$$Ek = Ek' \tag{4}$$

Where $Ek = \frac{p^2}{2m}$,

Ek = Kinetic Energy (Joule)
p = Momentum (Kg.m/s)
m = Mass of the Object (Kg)

TABLE 2. Kinetic energy before and after the collision

Position	Total Ek ($\times 10^{-3}$ Joule)
Before Collision	1.3
After Collision	0.72

TABLE 2 shows that the total kinetic energy before a collision is not the same as the total kinetic energy after a collision, so the value of the kinetic energy of an object did not meet the theory in EQUATION (4). This is because the collision between two objects is not elastic, and there is a loss of energy during the collision, which heat energy and sound energy have resulted from the collision of two objects.

From the data processing of the results of a one-dimensional motion experiment in the case of gravitational acceleration on an inclined plane and two-dimensional motion experiment in the case of collision of two objects, the result a good graph displaying an object's relationship with the position of the object's time. This is because the results of tracking are quite good related to regular object motion. In the case of gravitational acceleration and collision of two objects, using a 2D air track tool is designed by minimizing the friction, where the friction between the runway surface and the object that is sliding is very small. So that friction can be ignored, but not completely removed. The existence of 2D air track foundation tools can support the theory of Newton's II law equation, the law of conservation of momentum and kinetic energy, where these theories of friction in the matter are ignored (Pili &Violanda 2019).

CONCLUSION

The learning media development of 2D Tracker and digital camera-based air track on an experiment of one-dimensional motion, i.e., the experiment of an object gliding on an incline platform and an experiment of two-dimensional motion, i.e., the experiment of 2 objects collision can help and facilitate the teacher delivering the material and can help students understand the most basic physics concepts, namely motion. In selecting and using learning media appropriately, it can increase student motivation and encourage students to be more enthusiastic about participating in the learning delivered. Only small friction for objects in the 2D air track design so that the objects can be moved along their paths. Thus, the experiment of objects sliding on an inclined plane and the collision experiment of 2 objects, using a 2D Tracker and digital camera-based air track tool, can display various kinematics graphs and produce accurate analysis data, so that information about motion is complete.

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