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The Development of Educational Aids for Restitution Coefficient Experiment Using Microcontroller

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Abstract

This study aims to produce a product in the form of high school physics teaching aids for collision materials. The aids developed consist of Arduino as the central controller, photodiode sensor, and infrared sensor as ball motion detector mounted on the side of the tube track as high as 100 cm. The aids can record the time and altitude automatically on the bouncing ball. The research method used is R&D development research with the ADDIE model, which includes five stages, analysis, design, development, implementation, and evaluation. The variables used are variations in the type of ball and the pedestal type. Three types of balls are used: ping pong, golf, and tennis. The base types are ceramic floor, stainless steel, and acrylic. The ball bounce is an elastic collision partly because it has a restitution coefficient value of $0 < e < 1$. This experiment is done by ignoring air resistance and tracking friction. Students can make observations with the help of worksheets, which were also developed into the one-unit package. Through the validation test phase, the product has the worksheets get a value of 91% and the teaching aids 81%, which means that the worksheets and teaching aids are suitable for teaching materials to support learning physics.

Keywords: educational aids , microcontroller, worksheets, coefficient of restitution

INTRODUCTION

Learning physics for almost all students is identical to memorizing formulas and counting. Therefore, many students can only calculate using existing formulas without knowing the physics concept (Redish & Kuo 2015). The teacher feels that students prefer calculations and avoid questions that explain the mathematical relationship with physics (Lehavi et al. 2019). The same thing happens when studying the collisional matter, especially in finding the coefficient of restitution. Mathematically, the coefficient of restitution can be calculated using a negative ratio between the relative velocity just after the collision and the relative velocity before the collision (Shen et al. 2017).

Teaching aids facilitate learning the concept of the coefficient of restitution in class (Saepuzaman & Yustiandi 2017). Teaching aids are media that help the learning process (Indrasari, Rustana, & Zulfikar 2021). Teaching aids can help students to understand concepts better because the teaching aids are used to demonstrate a topic to be easily understood by students (Indrasari et al. 2021). In addition, teaching aids can improve student learning outcomes (Saepuzaman & Yustiandi 2017). Teaching aids in learning can make students actively involved, such as observing, conducting experiments, and demonstrations (Saepuzaman & Yustiandi 2017). Such learning activities are suitable for studying the coefficient of restitution.

The coefficient of restitution is closely related to the collision material. Both of these materials are contextual physical phenomena. In determining the coefficient of restitution, we must observe the collision event. The collision event occurred quickly, so a device capable of analyzing the event with high accuracy is needed. In the experiment of determining the restitution coefficient, the observation of motion parameters is generally still done manually. The manual experiment was made with simple equipment such as a ball and a ruler as a measuring tool. The position of the bounce height relies on the observer's accuracy, which is then measured using a ruler. This process is very susceptible to errors in measuring instruments' accuracy and observer subjectivity, especially if the data collected is more than one bounce (Indrasari, Budi & Fadilla 2021).

Based on these facts, a teaching aid is needed to determine the restitution coefficient to minimize data collection errors. Teachers generally have developed teaching aids to study the coefficient of restitution using a dramatic demonstration that is also simple and a very low-cost experiment of the direct collision of two balls in a vertical direction (Pattar & Joshi 2002). The difference is that the research conducted before by the other researcher (Saepuzaman & Yustiandi 2017) uses video tracking, the experiment must be recorded in advance. While the other research uses a microcontroller (Mughny & Rahmawati 2016). However, the results of this study still have a weakness, namely the need for a camera with a high resolution and reasonable frame rate per second. Some experimental data also show that the frame cannot capture the object's position when it reaches the maximum height or when the thing hits the floor (Saepuzaman & Yustiandi 2017). Utilizing other technologies such as microcontrollers that can replace the role of observers is through sensors (photodiode sensors and infrared sensors) and Arduino-based electronic control systems (one of the microcontrollers). The microcontroller is used as a digital system applied in households and the electronics industry (Wu, Qiu & Zhang 2020). The microcontroller is generally used as a control system, signal processing, instrumentation, and others (Ng 2016). The microcontroller can be used in learning activities as a learning medium to improve practical and programming skills. Microcontroller learning is currently one of students' basic knowledge lessons about technology and digital skills (Indrasari et al. 2021). The microcontroller is an open-source hardware prototyping platform that everyone can create programming-based projects (Ng 2016). Microcontrollers have been widely used in physics learning media, the benefits: physics experiments that were initially carried out with conventional methods can now be carried out efficiently, practically, and automatically. Therefore, Microcontroller expertise is critical in responding to technological challenges (Purahong 2013).

The teacher can train the microcontroller skills of students by conducting experiments or observations. Observations made by students using controller-based aids, of course, must require guidance such as worksheets (Indrasari, Rustana & Zulfikar 2021). A student worksheet is a student guide used to carry out the investigation or problem-solving activities. Student worksheets can be in the form of a guide for developing cognitive aspects or a guide for developing all aspects of learning in the form of an experimental or demonstration guide. A student worksheets contain assignments that students must do and can be used by all subjects, including physics. Worksheets are usually in the form of instructions steps to complete a task. A task order in the worksheet must be clear about the essential competencies to be achieved. The study is like observing a demonstration and taking data from the teaching aids used by the teacher.

Teaching aids following the material in learning is highly recommended because students can absorb learning material optimally, sincerely, and completely. In addition to listening to the explanation of the material, students can also be directly involved through seeing, touching, and experiencing it themselves. Teachers can also be more creative and prevent verbalism in conveying material if they use teaching aids to make physics learning more effective. So in this study, the development of teaching aids and worksheets will be carried out to find the coefficient of restitution. The tool is developed using a microcontroller with the results of measuring the height of the object being practiced can be displayed directly. This teaching aid has undergone development from previous research (Indrasari, Budi & Fadilla 2021; Indrasari, Budi & Fadilla 2020). In Indrasari, Budi & Fadilla (2021), it only uses tennis balls, while in Indrasari, Budi & Fadilla (2020), it only uses ceramic as a bounce base. This study will use aids with three types of balls: tennis, ping pong, and golf, while the bounce bases are ceramic, acrylic, and stainless steel. The worksheets developed to be used in conjunction with teaching aids are worksheets based on a scientific approach commonly known as the five essential learning experiences: observing, questioning, collecting information, associating, and communicating.

METHODS

This research method is Research and Development (RnD) using the ADDIE development model. The writer chose this model following the development of an Arduino microcontroller-based practicum tool by Apriliani, Permana, and Serevina (2019). The result of this research is a practicum tool equipped with student worksheets. The ADDIE diagram in this study can be seen in FIGURE 1.

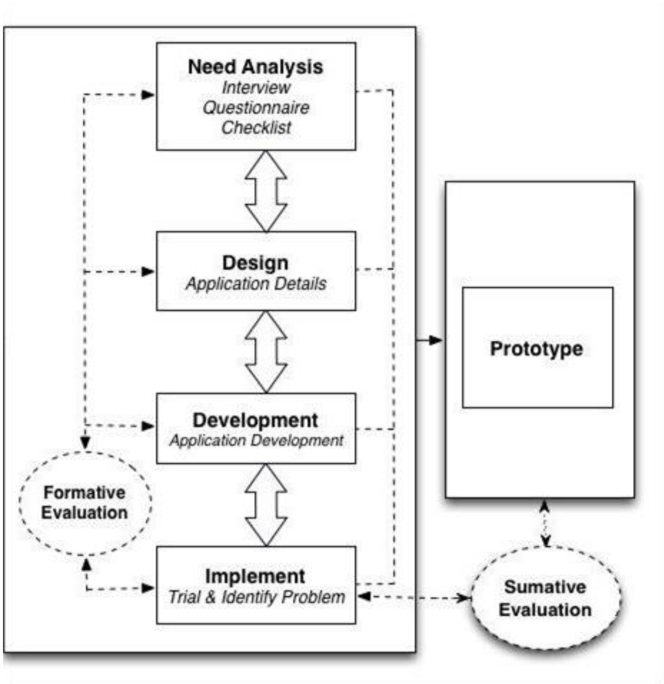


FIGURE 1. ADDIE diagram of this research (Nawi et al. 2015)

The stage of ADDIE consists of Analysis, Design, Development, Implementation, and Evaluation. Each stage will be explained as follows:

- The analysis includes a preliminary study of problem identification or gaps and possible causes of gaps. Necessary activities analyzed are to analyze the applicable curriculum, learning objectives and competencies to be achieved, the type of material or topics presented, targets/students, and the method of presentation.
- The design step is related to goal setting, assessment instruments, exercises, content, and analysis related to learning materials, lesson plans, and media selection. Activities in the design begin with designing an outline (components) of the product to be developed, then proceed with the systematic preparation of the developed product.
- The development stage includes preparing materials for the product to be developed or appropriate aids. The following tools and materials need to be prepared:
  1. Arduino Mega 2560.
  2. Photodiodes 99 pieces.
  3. Infrared 99 pieces.
  4. Electronic black box.
  5. USB cable.
  6. Laptop Devices.
  7. Acrylic tube diameter 8cm, height 100cm, and thickness 3 mm.
  8. Ball (ping pong, golf, tennis).
  9. Base (acrylic, stainless steel, ceramic).

10. Track framework (iron rods, supports, handles/holders, bolts).

Then to find out the stages of work in general in designing the system, a block diagram can be made, as shown in FIGURE 2.

FIGURE 2. Block diagram of teaching aids

Based on the block diagram above, here is a brief explanation of the function of each block:

1. Infrared light in this tool provides a logical condition of one to the receiving sensor.
2. The receiving sensor serves to determine whether objects cover the infrared light or not or, in other words, as a light detector. This receiving sensor is a photodiode.
3. The microcontroller is the control center of this tool. Arduino will change the input from the sensor and then processes it, which will produce the value of height.
4. The data processor used is Arduino IDE and Microsoft Excel, which data storage and processing.

- The implementation stage is if the product is feasible as a physics learning medium, then the product is ready to be applied or implemented to support learning activities in school.
- The evaluation carried out is divided into two types, namely formative and summative evaluations. Formative evaluation is carried out at each step when the product manufacturing process is in progress. Meanwhile, evaluating at the end of making a product after completing the series is called a summative evaluation.

The data collection technique used in testing the teaching aids is repeated measurements five times in each condition. The five data that have been obtained are then processed. As for the technique of collecting data from this research, a questionnaire was used with a calculation scale using a Likert scale. Questionnaires in product evaluation and product implementation questionnaires were given to validators and product trials by respondents.

RESULTS AND DISCUSSION

Worksheet

Learning media experts have validated the worksheets with content suitability assessment and usage efficiency indicators. The item assessed based on the suitability of the content is whether the worksheet can complement the teaching aids. At the same time, efficiency is seen in whether the developed worksheets facilitate the learning process with teaching aids. The validation value can be seen in TABLE 1.

TABLE 1. Worksheet validation results

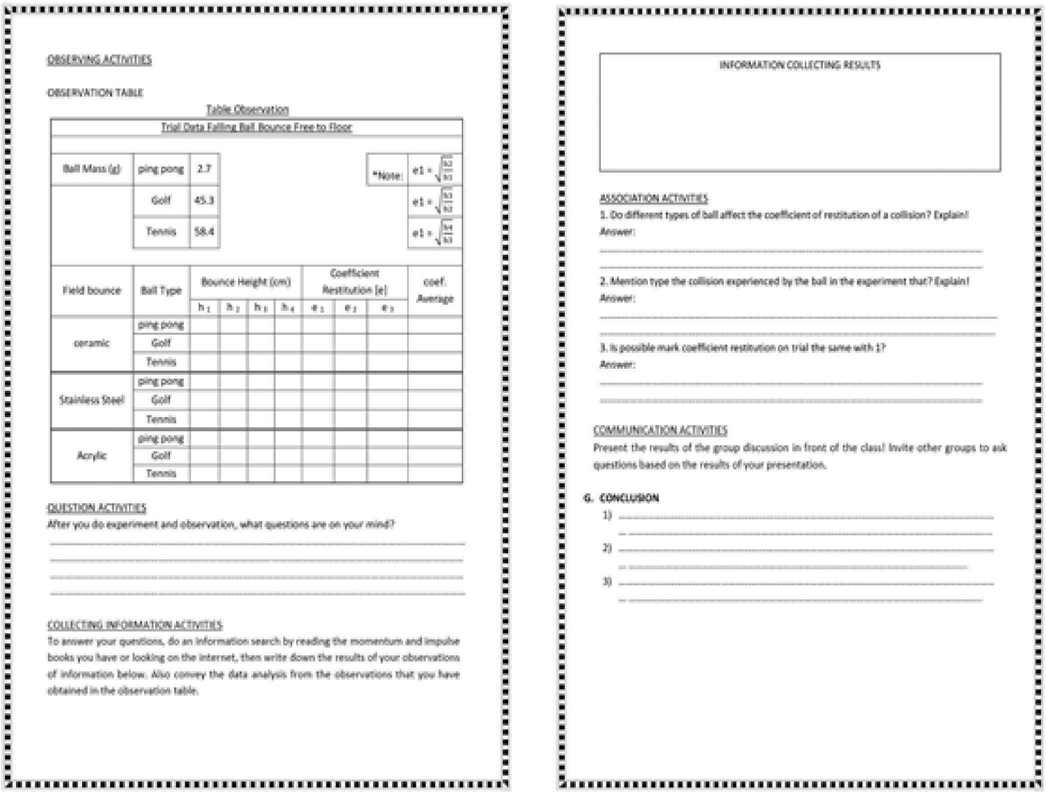
No	Indicator	Value Percentage (%)	Interpretation
1.	The suitability of the content	94	Good
2.	The efficiency	88	Good
	Average	91	Good

The worksheets that have been made have been integrated with a scientific approach, namely observing, questioning, collecting information, associating, and communicating. Each stage of the scientific approach is presented in FIGURE 3. The following explains how the scientific approach is applied in the worksheet, and this is also following the laboratory activity for students, which begins by considering the primary objectives of laboratory activities: studying experimental processes, physical experiences, practicing skills/procedures, collecting, or analyzing data, working collaboratively, etc. (Clough 2007).

- Observing: train seriousness accuracy and seek information by observing the ball's fall using aids. This section also provides a table of observations.

- Questioning: students are given questions based on experiments or observations made using aids on the worksheet.
- Collecting information: the activities carried out on the worksheets invite students to conduct experiments and read other sources related to momentum and impulses (reading sources other than textbooks).
- Associating: students use the data or information that has been collected to answer the hypothesis. In this step, the worksheet asks several questions that direct students to relate the data/information obtained to conclude, such as whether the ball affects the collision restitution coefficient and what kind of collision the ball experiences.

Communicating: students provide answers to the questions orally using presentations. In addition, students ask their friends to ask questions.



OBSERVING ACTIVITIES

OBSERVATION TABLE

Table Observation

Trial Data Falling Ball Bounce Free to Floor

Ball Mass (g)			
ping pong	2.7	*Note:	$e1 = \sqrt{\frac{h2}{h1}}$
Golf	45.3		$e1 = \sqrt{\frac{h3}{h2}}$
Tennis	58.4		$e1 = \sqrt{\frac{h4}{h3}}$

Field bounce	Ball Type	Bounce Height (cm)				Coefficient Restitution (e)			coef. Average
		h_1	h_2	h_3	h_4	e_1	e_2	e_3	
ceramic	ping pong								
	Golf								
	Tennis								
Stainless Steel	ping pong								
	Golf								
	Tennis								
Acrylic	ping pong								
	Golf								
	Tennis								

QUESTION ACTIVITIES

After you do experiment and observation, what questions are on your mind?

COLLECTING INFORMATION ACTIVITIES

To answer your questions, do an information search by reading the momentum and impulse books you have or looking on the internet, then write down the results of your observations of information below. Also convey the data analysis from the observations that you have obtained in the observation table.

INFORMATION COLLECTING RESULTS

ASSOCIATION ACTIVITIES

1. Do different types of ball affect the coefficient of restitution of a collision? Explain!
Answer:

2. Mention type the collision experienced by the ball in the experiment that? Explain!
Answer:

3. Is possible mark coefficient restitution on trial the same with 1?
Answer:

COMMUNICATION ACTIVITIES

Present the results of the group discussion in front of the class! Invite other groups to ask questions based on the results of your presentation.

G. CONCLUSION

1)

2)

3)

FIGURE 3. Worksheets consist of observation, question, collecting information stage, association, and communication.

Microcontroller Aids

Aids are a tool used to help make it easier to understand a concept indirectly. The aid developed is a tool to show collision events using an Arduino microcontroller. Overall the collision aids developed consisted of several components, namely: 1. Trajectory Framework (FIGURE 4), 2. Electronic Box (FIGURE 5), 3. Computer Equipment (FIGURE 6), 4. Ball object and bounce base (FIGURE 7). The characteristics of the ball and the bounce base used in teaching aids can be seen in TABLE 4. This teaching aid will generally observe the collision process between three different balls with three other bases. The data obtained is in the height of the object's bounce. From the height of the bounce, students can use it to analyze the type of collision and the coefficient of restitution.

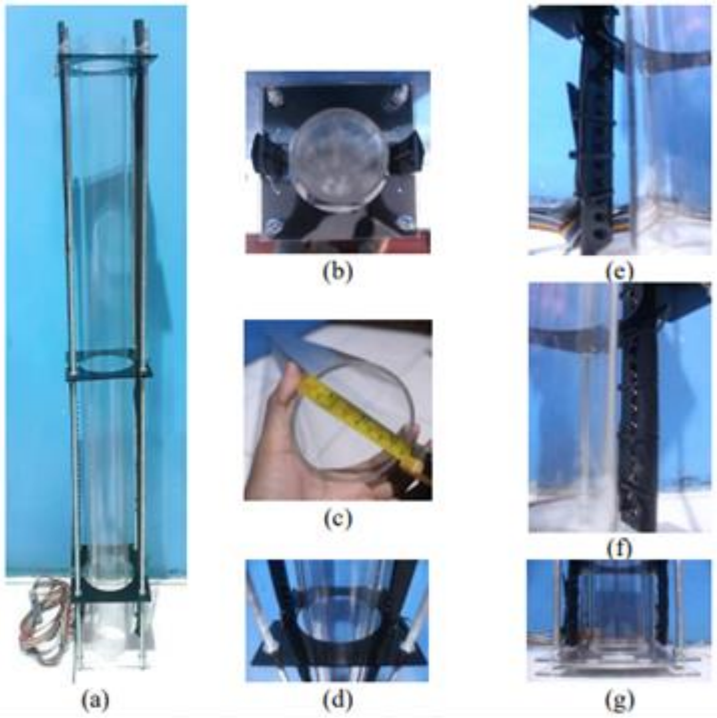


FIGURE 4. (a) Overall view, (b) Top view, (c) Trajectory tube, (d) Holder, (e) Photodiode sensor, (f) Infrared sensor, (g) Bottom view of the track frame

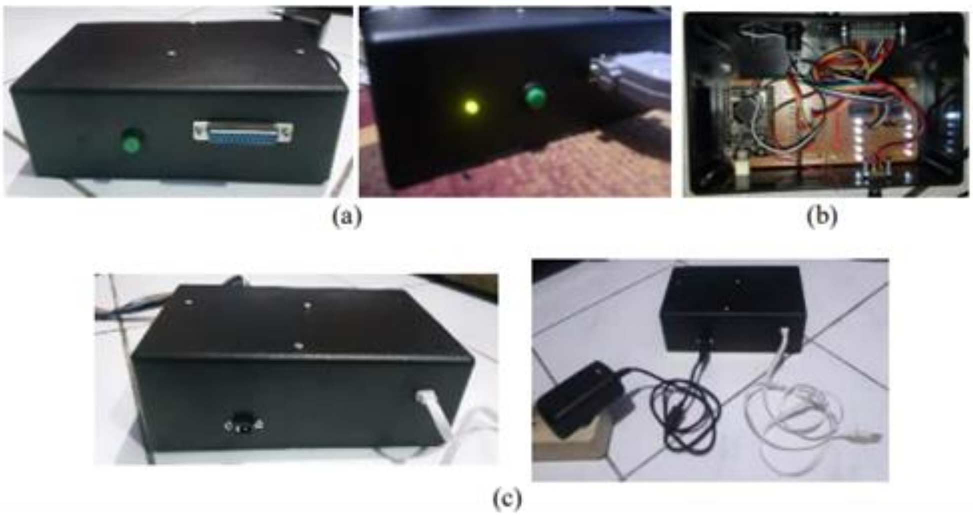


FIGURE 5. (a) Front view, (b) Contents of the electronics box, (c) Back view

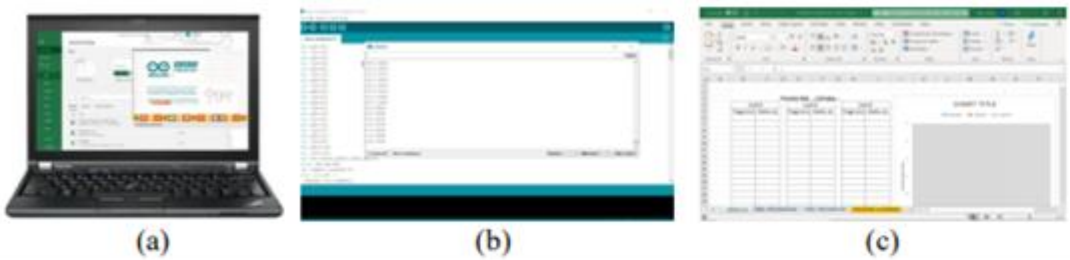


FIGURE 6. (a) Laptop, (b) Arduino IDE, (c) Microsoft Excel

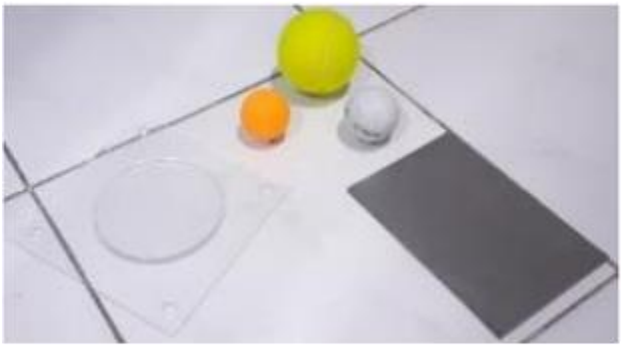


FIGURE 7. Variations of the ball and the base of the bounce

The teaching aids developed have also been validated by learning media experts. Assessment indicators include content suitability, concept suitability, interactivity, design suitability, effectiveness, and efficiency. The results of the expert assessment can be seen in TABLE 2. At the time, the validator evaluation gave a suggestion. The suggestion is that each aid component is given a label or name to be user-friendly. The results of the revision can be seen in FIGURE 8.

TABLE 2. Microcontroller aids validation results

No	Indicator	Value Percentage (%)	Interpretation
1.	The content suitability	82	Good
2.	The concept suitability	78	Good
3.	The interactivity	80	Good
4.	The design suitability	81	Good
5.	The effectiveness and efficiency	83	Good
	Average	81	Good

FIGURE 8. Revision aid by giving a label on each component

Discussion

Both worksheet validation and teaching aids both use a questionnaire. Then the results were processed by getting the following score ranges in TABLE 3. Therefore, the scores obtained indicate the validity and quality of the teaching aids. The higher the value, the more qualified and suitable to be used as a teaching aid (Putri & Suwarna 2020). The questionnaire instrument must be valid so that the assessment indicators are clear and measurable. In this assessment, the questionnaire was taken from similar research (Permana et al. 2021) and adjusted.

TABLE 3. The test results

Percentage Rate (%)	Interpretation
85-100	Very good
65-84	Good
55-64	Average
0-54	Bad

Product trials are carried out on a small/limited lab scale after being declared feasible. The goal is to determine whether the developed teaching aids can work according to their functions. The aid system can record altitude data for 4 seconds every 5.5 ms. TABLE 4 shows the standard deviation value is low, which means the data is close to the average and has a wide range of data variations. The most significant relative error in the test is shown in tennis balls; this is because the diameter of the ball is only ± 2 cm from the diameter of the track tube, causing a large amount of friction between the ball and the wall of the track tube. Factors of deviation, uncertainty, or other errors for all tests in the measurement of the collision travel time and the height of the ball's bounce are due to the influence of the motion of the bouncing ball that is not entirely vertical, and the ball rotates. This causes friction against the tube and friction with the air, which hinders the ball's motion. Because it only pays attention to the maximum height of the ball's bounce, the influence of other uncertainties is the velocity of the falling object and the contact time of the ball with the floor during the collision, which is neglected in the test.

TABLE 4. The test results

The ball	Base bounce	Restitution Coefficient	Relative Error (%)
Golf	Ceramic	0.901 ± 0.014	1.552
	Acrylic	0.889 ± 0.016	1.835
	Stainless steel	0.797 ± 0.028	3.669
Ping pong	Ceramic	0.806 ± 0.015	1.822
	Acrylic	0.805 ± 0.023	2.818
	Stainless steel	0.800 ± 0.011	1.330
Tennis	Ceramic	0.656 ± 0.039	5.954
	Acrylic	0.634 ± 0.024	3.808
	Stainless steel	0.533 ± 0.032	5.639

TABLE 4 shows experimental data that has been processed, where each experiment was repeated five times for data collection. Data collection five times supported by similar research (Saepuzaman & Yustiandi 2017). Based on TABLE 4, it can be seen that golf balls with ceramic, acrylic, and stainless steel bounce base have high coefficient values when compared to ping pong balls and tennis balls. This is because golf balls are hard and solid balls. The dimples on the golf ball have a particular function. Dimples are depressions commonly seen on golf balls. The concave-convexity affects the movement of golf balls to help golf balls fly further so that the distance traveled can be other. In this case, the dimples in the golf ball also help lift the ball by pushing the air pressure down and causing the ball to lift upwards. In other words, these dimples will reduce the frictional force on the ball so that the ball has dimples that will move more away from a ball with a smooth surface (Arief & Adjie 2019).

For a ping pong ball with a smooth/flat surface, the coefficient of restitution tends to be the same or insignificant if it collides with ceramic, acrylic, or stainless steel bouncing surfaces. This happens because ping-pong is a hollow ball and is made from light celluloid plastic. Meanwhile, tennis balls that collide with ceramic, acrylic, or stainless steel bouncing planes have the lowest coefficient values compared to the previous two balls. Court tennis balls made of rubber with a surface layer of fur or soft threads affect the ball's motion to slightly slow down the ball's speed when it is in the air. Based on experiments, it is known that the ball's hardness affects the value of the coefficient restitution. A hardball has a significant coefficient of restitution. Then, if sorted, the balls with a significant coefficient of restitution are as follows: golf ball > ping pong > tennis. The data in Table 4 above also shows the effect of the bounced field on the coefficient of restitution. The decrease in the value of the coefficient of restitution because of energy loss during the collision. That is proven by the bounce base or the impact surface changes from a hard object to a softer thing. Ceramic has the highest coefficient of restitution, then acrylic and stainless steel are the lowest. This proves the hardness of the reflecting plane of ceramic > acrylic > stainless steel.

The experimental results obtained are different from the research conducted by Yang et al. (2011). Yang et al. (2011) showed that the stainless steel coefficient of restitution was greater than acrylic. This could be due to the difference in the material used by Yang et al. (2011) and the author. The advantage of the Yang et al. (2011) experiment is that it calculates the damping coefficient and the material properties of each material used. Likewise, with the comparison of the results of the ball experiment used by the author and other researchers. Ribeiro et al. (2012) found that hollow plastic balls had the most significant coefficient of restitution when compared to heavy solid balls. In the Ribeiro (2012) experiment, the base used as the reflecting plane is only a table, but the character of the table is not explained

CONCLUSION

Based on the explanation above, it can be concluded that the teaching aids using a microcontroller and worksheets have been successfully developed for an experiment to determine the coefficient of restitution. The aid can prove that the bounce of the ball with the base is a partially elastic collision and produces a restitution coefficient value ranging from $0 < e < 1$. Meanwhile, the developed worksheets get a validation value of 91, which indicates that the worksheets are suitable to be used as teaching materials to support physics learning.

REFERENCES

Apriliani, A, Permana, AH & Serevina, V 2019, 'Pengembangan Set Praktikum Rangkaian Listrik Arus Searah Menggunakan Data Logger Dan Arduino Uno', *Thesis*, UNJ, Jakarta.

Arief, IS & Adjie, RW 2019, 'Developing Experimental of Dimple Effect Applied on Flat Plate against Fluid Flow', *International Journal of Marine Engineering Innovation and Research*, vol. 4, pp. 69-77.

Clough, M 2007, 'Learning and teaching in the school science laboratory: An analysis of research, theory and practice', *In book: Handbook of Research on Science Education*, Lawrence Erlbaum Associates.

Indrasari W, Rustana, CE & Zulfikar, Z 2021, 'Development a practicum tools to measure the speed of the air using Arduino Uno Microcontroller', *Journal of Physics: Conference Series*, vol. 1816, p. 012109.

Indrasari, W, Budi, A & Fadilla, D 2021, 'Development of a set of aids for collision based on Arduino Uno Microcontroller', *Journal of Physics: Conference Series*, vol. 1816, p. 012107.

Indrasari, W, Budi, AS & Fadilla, DP 2020, 'Rancang Bangun Alat Peraga Tumbukan Berbasis Mikrokontroller Untuk SMA', *Prosiding Seminar Nasional Fisika (E-JOURNAL*), vol. 9, SNF2020PF-91.

Indrasari, W, Rustana, CE, Arifin, F & Muliyati, D 2021, 'Development of beat frequency practicum device using Arduino UNO and AD9833 module', *AIP Conference Proceedings*, vol. 2320, p. 050041.

Lehavi Y, Mualem R, Bagno E, Eylon BS & Pospiech G 2019, 'Taking the Phys-Math Interplay from Research into Practice', *Mathematics in Physics Education*, pp. 335-353.

Nawi, A, Hamzah, M, Ren, C & Tamuri, AH 2015, 'Adoption of Mobile Technology for Teaching Preparation in Improving Teaching Quality of Teachers', *International Journal of Instruction*, vol. 8, pp. 113-124.

Ng, TS 2016, 'Microcontroller', *Real Time Control Engineering, Studies in Systems, Decision and Control*, vol. 65, pp. 39-77.

Pattar, U & Joshi, AW 2002, 'Head-on collision of two balls revisited', *Reson*, vol. 7, pp. 67-77.

Permana, H et al. 2021, 'The Development of Augmented Reality Application to Explore Fluid Concepts', *Jurnal Penelitian & Pengembangan Pendidikan Fisika*, vol. 7, pp. 53-60.

Purahong, B 2013, 'Learning the basics of microcontroller starter kit boards AVR (eSnack)', *Proceedings of 2013 IEEE International Conference on Teaching, Assessment and Learning for Engineering (TALE)*, pp. 29-32.

Putri, SE & Suwarna, IP 2020, 'The Experimental Study of Kinesthetic Style Student Learning Outcomes in Remedial Teaching Assisted by Projectile Motion Props', *Jurnal Penelitian & Pengembangan Pendidikan Fisika,* vol. 6, pp. 25-36.

Redish, EF & Kuo, E 2015, 'Language of Physics, Language of Math: Disciplinary Culture and Dynamic Epistemology', *Sci & Educ*, vol. 24, pp. 561-590.

Ribeiro, T, Romero, J, Andrade-Romero, JA 2012, 'Novel Techniches for Experimental Determination of The Restitution Coefficient by Means of Acoustic Signal Analysis', *ABCM Symposium Series in Mechatronics*, vol. 5, pp. 676-683.

Saepuzaman, D & Yustiandi, Y 2017, 'Pengembangan Alat Peraga dan Lembar Kerja Percobaan Penentuan Koefisien Restitusi untuk Meningkatkan Kemampuan Siswa Bereksperimen', *Jurnal Penelitian & Pengembangan Pendidikan Fisika*, vol. 3, pp. 145-150.

Shen, F, Wang, Y, Shen, C et al. 2017, 'On the Collision Nature of Two Coronal Mass Ejections', *A Review. Sol Phys*, vol. 292, 104.

Wu, Z, Qiu, K & Zhang, J 2020, 'A Smart Microcontroller Architecture for the Internet of Things', *Sensors*, vol. 20, p. 1821.

Yang, J, Silvestro, C, Khatri, D, De Nardo, L & Daraio, C 2011, 'Interaction of highly nonlinear solitary waves with linear elastic media', *Physical review. E, Statistical, nonlinear, and soft matter physics,* vol. 83, p. 046606.