Development of Affordable Pendulum and Collision Prop as Media in Science Learning

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***Abstract* – The problems related to science learning media are the high cost and the need to be ably, hence an affordable pendulum and collision learning prop (AOPC) is developed. This research aims to develop AOPC that is valid and practical for use in science courses while aligning with related scientific theory. The research followed a research and development design, meeting the required standards and criteria. The research findings demonstrate that AOPC aligns closely with theoretical expectations, and fulfills the validity and practicality tests. Research implies the development of affordable learning aids, especially in rural areas, where they can implement effective learning processes.**

***Keywords* – Affordable, collision, education, pendulum, science learning.**

1. Introduction

In science education, the effective use of teaching aids and instructional media plays a crucial role in enhancing students' understanding and engagement [1]. However, many schools and educators face challenges in accessing affordable and practical teaching tools for science concepts.

The existing options available in the market are often expensive, limiting their accessibility to a wide range of educational institutions. This situation hinders students' opportunities to explore and grasp fundamental science principles. The lack of affordable and accessible teaching props deprives students of hands-on experiences, hindering their conceptual understanding development in these areas.

The development of a prop as science learning media can be considered a viable solution to address the problem because the media are one of the success factors in the learning process [2]. This can be seen when physical props and images enhance the teaching and learning process by making it more active and engaging. Props as science learning media can be used in role-playing exercises to simulate real-world problem-solving scenarios because science is related to authentic phenomena [3]. This can help students develop critical thinking skills and apply their knowledge to practical situations [4], leading to better problem-solving skills. Some previous research created science learning props, such as arduino based-props for collision material [5], personal desk laboratory [6], dynamic fluid props [7], and smart aquariums [8], as a valid and practical science learning media so that it is worth considering to be applied in science learning, including for students with special needs.

However, the process of developing props must consider field conditions and existing facts, including the material taught. For instance, [9] discovered that most students experience misconceptions about the pendulum and harmonical motion. Another researcher revealed that students generally still experience misconceptions in the context of pendulum motion [10]. Not only that, but some studies also reveal that learners tend to experience misconceptions about momentum and impulse material [11], [12].

Some previous research has actually developed props on both materials, like [13], [14] designed props on simple pendulum materials based on Micro-electromechanical systems, IoT-based microcontrollers, and Arduino uno.

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Meanwhile, [5], [15] also developed a set of props for collision-momentum materials based on arduino microcontroller. Nonetheless, developing such props requires sophisticated technology that is relatively difficult to access in rural and remote areas. Not to mention, tools and materials are relatively more expensive and difficult to find in the area. Hence, the media needs to be packaged in a form that is simpler, cheaper, and easier to design.

Therefore, this research aims to develop an affordable pendulum and collision prop (AOPC), especially for science learning media. AOPC can be used at secondary school, high school, and university levels, adapting to the use of the prop. Referring to Nieveen [16], educational product development should fulfill valid and practical criteria to achieve quality. As a result, this study aims to investigate the validity of AOPC as a science learning media.

2. Materials and Method

This study uses research and development design with analysis, design, development, implementation, and evaluation (ADDIE) approach, which is only limited to the development stage as an initial development process [17]. The feasibility of the product under development was tested through validation, theoretical testing, and limited trials. The research was conducted between May and August 2022. The research stages are illustrated in Figure 1.

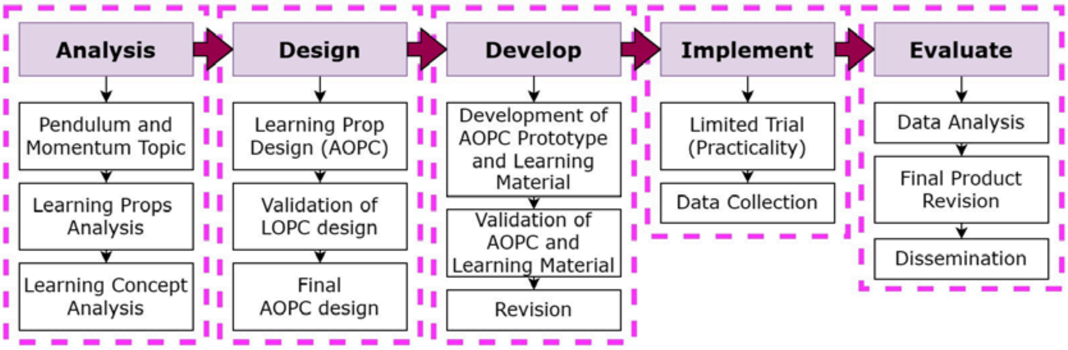

Figure 1. Research process

The research process commenced with the initial design of AOPC using Blender 3.1 software as a preliminary draft. Subsequently, focus group discussions were conducted with science education experts to evaluate the designed props' functionality and feasibility. Following improvements and revisions to the initial design, as depicted in Figure 2, the next stage involved product development. The development process yielded drafts of AOPC products as science learning media. The drafts were then evaluated by two science education experts and one physics instrumentation expert. As the results were deemed suitable with revisions, the product could be tested on a limited group of pre-service physics teachers.

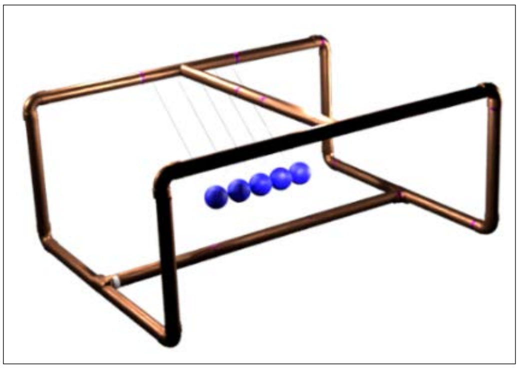

Figure 2. AOPC initial design

The data collection process initiates with the development of all the instruments and AOPC, followed by experts' assessment of their validity. The validity aspect includes evaluating the content and construct of each instrument and AOPC [16]. The instrument employed for data collection at this stage is an expert questionnaire. The subsequent step is the practicality test once the instrument and prop have been deemed valid with several revisions. During this stage, the practicality of AOPC is assessed by two physics laboratory assistants, one in-service science teacher, and 20 pre-service physics teachers. The practical dimensions of AOPC assessed include effectiveness, creativity, efficiency, and maintenance [18].

The validity data were subjected to descriptive analysis by calculating the average value according to the criteria outlined in Table 1. Furthermore, the validity of the data was assessed statistically using the corrected item-total correlation, where an instrument is considered valid if the value of $r_\alpha \geq 0.4$ [19]. The validity assessment also served as a basis for measuring the reliability of the instrument and AOPC through the Cronbach Alpha value, with a threshold of $\alpha \geq 0.7$ [20]. Regarding the analysis of practicality data, a descriptive approach was employed by calculating the average for each dimension, guided by the criteria specified in Table 1.

Table 1. Criteria of validity and practicality

Validity		Practicality	
Score	**Criteria**	**Score**	**Criteria**
3.25 – 4.00	Very Valid	≥ 4.00	Very Practical
2.50 – 3.24	Valid	3.00 – 3.99	Practical
1.75 – 2.49	Less Valid	2.00 – 2.99	Quite Practical
1.00 – 1.74	Invalid	1.00 – 1.99	Impractical
		≤ 1.00	Very Impractical

3. An Overview of AOPC

The AOPC is an affordable prop, as its development process only costs US $6-10. This prop is versatile and can be used for three types of experiments: collisions, simple mathematical pendulums, and damped oscillations. The selection of the experiment type is tailored to the learners' educational level. The main components of the AOPC consist of pipes and ropes that connect the two sides of the tool, as well as a diagonal rope. These ropes can be attached to a load, such as a ball. In momentum and collision experiments, balls with different masses and quantities can be used and swung at specific angles. The diagonal pipe at the top of the tool is utilized for the mathematical pendulum experiment. A single pendulum can be hung from the pipe, allowing manipulation of rope lengths and swing angles to determine the acceleration of gravity. Similar experiments can also be conducted to determine the coefficients of damped oscillation or vibrational motion using applications like Tracker Video Analysis [21].

Figure 3. Simple collision experiment

The results of tests on momentum and impulse experiments, as presented in Figure 3, show that the collision that occurs is perfect bending, where when the ball is distorted at an angle of 5° there is a collision process 4 times, at 15° 5 times, 30° 6 times, and 45° 7 times. Thus, the greater the angle of intersection, the greater the number of collisions. This observation aligns with the concept of conservation of momentum. When an object deviates at a larger angle after a collision, it implies a larger change in its momentum [22].

This change in momentum can be attributed to a greater force exerted during the collision, resulting in a higher number of collisions. In addition to momentum conservation, energy conservation also plays a role in collisions. If an object deviates at a larger angle, it indicates a transfer of kinetic energy during the collision. This energy transfer may occur in more elastic collisions, where a greater amount of energy is transferred between the objects, leading to an increased number of collisions [23].

Furthermore, another factor that can affect the number of collisions is the object's density. This is due to the fact that density can also impact the elasticity and deformation of objects involved in a collision. Elastic collisions involve a temporary deformation of the objects followed by their restoration to their original shape. The density of an object can affect its elasticity and how it deforms during a collision. Objects with higher density may be more rigid and less prone to deformation, resulting in different collision characteristics compared to objects with lower density [24]. Notably, several other factors can affect this simple experiment activity, such as density, deviation angle, and number of balls. Students' may investigate those influencing variables in order to enrich their learning knowledge and experience.

In simple mathematical pendulum experiments, the activities that can be done are to prove the gravitational acceleration constant of 9.8 m/s^2 while investigating the relationship between the length of the rope and the pendulum period [22]. It should be noted that experimental activities are carried out simply at the high school level, so it is necessary to avoid advanced experimental techniques that can make students difficult to understand the experiment. The steps in this experiment begin by determining the length of the rope and the angle of intersection; after that, the pendulum is released without initial speed and measures the time using the stopwatch simultaneously until the pendulum has vibrated five times.

Table 2. AOPC theoretical testing on the simple mathematical pendulum topic

(L ± 0.05) m	n	t (s)	T (s)	g (m/s^2)
0.10	5	2.03	0.41	9.71
0.15	5	3.07	0.61	9.63
0.20	5	4.05	0.81	9.73
0.25	5	5.03	1.01	9.80
0.30	5	6.07	1.21	9.74

The results of the experiments can be seen in Table 2, where the longer the rope, the longer the period of time it takes to take five vibrations.

According to simple harmonic motion principles, a pendulum's period is directly proportional to the square root of its length. This relationship can be mathematically expressed as $T = 2\pi\sqrt{(L/g)}$ [24]. When the pendulum's length is increased, the square root of the length also increases. As a result, the period of the pendulum becomes longer. This can be understood intuitively by considering that a longer pendulum needs more time to complete a full swing due to the increased distance it has to cover. In terms of gravitational acceleration proof, it can be seen that the value is not precise at 9.8 m/s^2. This is due to several factors, such as the use of conventional measuring instruments and air friction forces that inhibit the ball's movement [25]. Nonetheless, overall, the average value of gravitational acceleration obtained is 9.72, close to the theoretical constant. In addition, it is necessary to repeat each experiment to get more accurate data.

The third experimental topic focused on damped oscillations, where students were tasked with investigating a specific type of harmonic motion based on its characteristics. According to the theory, damped oscillation can be classified into three types: strong damping, critical damping, and weak damping [26]. The distinguishing factor among these types lies in the speed at which the vibration amplitude approaches zero. Furthermore, when the ball is swung, it exhibits underdamped behavior as the pendulum oscillates for an extended period and crosses the equilibrium position multiple times [27]. This topic is particularly relevant for university-level students taking classical mechanics courses. The experimental setup, as depicted in Figure 4, involves the following steps: initiating the pendulum's motion with a specific deviation angle while recording a video using a mobile phone until the pendulum completes its vibration; subsequently, the video can be processed and analyzed using Tracker Video Analysis software to determine the appropriate equation of fit and relevant physical quantities [28].

Figure 4. Set up apparatus for damped oscillation experiment

Figure 5 depicts the x-t graph formed based on tracking results using the software.

It can be interpreted that the number of vibrations that occur until the pendulum completely stops is so large that the graph formed is almost invisible. However, the type of attenuation that occurs is a small attenuation. It can be known that there is a large decrease in amplitude ranging from t = 10 to t = 150. Small damping has the characteristic that the value $\gamma^2 < 4\omega_o^2$ [29], where the value of γ can be seen in parameter B, which is 6.90. After knowing the value of γ, the next is to determine the ω_o^2 value as follows.

$$\omega_0^2 = \frac{g}{l}\ ;\ \omega_0 = \sqrt{\frac{g}{l}} = \sqrt{\frac{9.8}{0.15}} = 8.08$$

Due to the value of $\gamma^2 < 4\omega_o^2$ (47.61 < 261.14), so it can be concluded that the type of damping that occurs is small. This means that according to observations graphically and calculations in theory, there are similarities so that the experiments conducted align with the theory.

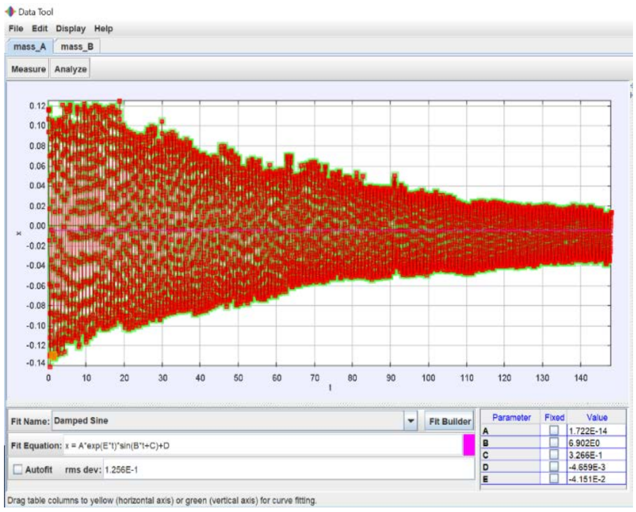

Figure 5. Damped oscillation motion tracking results using tracker software

4. Validity of AOPC

Expert validity was chosen to assess the feasibility of the research instrument and the AOPC, as illustrated in Table 3. Validity targets the content and constructs of each instrument. Overall, the instruments demonstrate strong validity and reliability, including the learning module, teaching material, student's worksheet, test instrument, student's questionnaire, and AOPC. This suggests that these instruments are well-suited for the research study and can provide accurate and consistent measurements of the intended constructs. According to experts, the instruments are suitable for use after minor revisions. After minor revisions, the instruments can be tested for its practicality.

Table 3. AOPC validity assessment

Validity Assessment		r_α	Validity Criteria	α	Reliability
Content	**Construct**				
3.46	3.53	0.98	Very Valid	0.98	Reliable

Valid AOPC means that the collected data can accurately measure the tool's functionality, increasing the credibility and trustworthiness of the research findings. Additionally, reliable assessment tools help educators make informed decisions about student performance and progress. Some researchers confirmed that valid science props are able to give students' learning outcomes completeness and increase their concept understanding [30]. Thus, the prop is feasible to be used as media in science learning.

5. Practicality of AOPC

The practicality of AOPC is evaluated by science teachers and laboratory assistants, who serve as practitioners, as well as pre-service physics teachers, who act as users. The outcomes of the practicality assessment for AOPC are presented in Table 4. Overall, AOPC demonstrates a high level of practicality based on the assessment results, particularly in terms of effectiveness, creativity, and maintenance. However, the efficiency aspect receives a lower rating compared to the other aspects. According to the assessors, there is a need to refine the packaging of AOPC to enhance its portability and ease of transportation.

Table 4. AOPC practicality assessment

Practicality Aspects	Teacher and Lab Assistant Assessment		Pre-service Physics Teacher Assessment	
	Score	**Criteria**	**Score**	**Criteria**
Effectiveness	4.50	Very Practical	4.52	Very Practical
Creativity	4.67	Very Practical	4.47	Very Practical
Efficiency	3.89	Practical	4.25	Very Practical
Maintenance	4.67	Very Practical	4.66	Very Practical
Average	4.43	Very Practical	4.47	Very Practical

The effectiveness aspect represents that AOPC can help students improve learning outcomes in the materials on momentum, simple mathematical pendulums, and damped oscillations. The prop accuracy to support the delivery of material is necessary because it can increase their understanding and prevent misconceptions. Moreover, effective learning props generally get a positive response from students [31]. In terms of creativity, it refers to prop design that can make students interested in using it and actively participate in learning. Creative learning media capture learners' attention and spark their interest, making the learning process more engaging and enjoyable. It motivates students to actively participate, explore, and retain information better [32].

Furthermore, on the efficiency aspect, the prop has flexibility in carrying and use, and no special skills are needed. Flexible learning media promote accessibility by providing options for learners with different abilities and learning challenges, in order to provide convenience for its users [33]. Finally, the maintenance aspect indicates that the prop is easy to maintain and repair in case of breakdown.

This convenience means educators in rural areas do not need to go to the city to repair the prop, because the tools and materials are more affordable and easy to find.

6. Conclusion

The research findings generally highlight that AOPC has been tested internally based on general physics or science theories. According to development criterion, AOPC has fulfilled an empirical quality criterion: valid and practical. Therefore, the prop can be used as media in science learning to implement effective teaching, improving students' learning outcomes. In spite of being very conventional at a low cost, the prototype has a positive influence on aspects of science learning. Designing a low-cost prop makes it more accessible to a broader range of schools and students, eliminating financial barriers that may hinder hands-on learning experiences. This affordability allows for greater inclusivity and equal opportunities for students to engage in experimental science, regardless of their socioeconomic background.

References:

[1]. Kumar, T., Malabar, S., Benyo, A., & Amal, B. K. (2021). Analyzing multimedia tools and language teaching. *Linguistics and Culture Review*, *5*(S1), 331-341.

[2]. Weinstein, Y., Madan, C. R., & Sumeracki, M. A. (2018). Teaching the science of learning. *Cognitive Research: Principles and Implications*, *3*, 2. Doi: 10.1186/s41235-017-0087-y

[3]. Jan, H. U., Uddin, M., Shah, I. A., & Khan, S. U. (2022). On the eventual periodicity of fractional order dispersive wave equations using RBFS and transform. *EUREKA: Physics and Engineering*, *3*, 133–148. Doi: 10.21303/2461-4262.2022.002394

[4]. Negoro, R. A., Rusilowati, A., & Aji, M. P. (2023). Scratch-Assisted Waves Teaching Materials: ICT Literacy and Students' Critical Thinking Skills. *Journal of Turkish Science Education*, *20*(1), 189–210. Doi: 10.36681/tused.2023.011

[5]. Indrasari, W., Budi, A. S., & Fadilla, D. P. (2021). Development of a set of props for collision based on Arduino Uno Microcontroller. *Journal of Physics: Conference Series*, *1816*(1), 12107. Doi: 10.1088/1742-6596/1816/1/012107

[6]. Wahyuni, H. S., & Rosana, D. (2019). Physics Props Development based on Personal Desk Laboratory System to Improve Creative Thinking Ability and Students' Scientific Attitude. *Journal of Physics: Conference Series*, *1233*(1), 12032. Doi: 10.1088/1742-6596/1233/1/012032

[7]. Rahmayani, Rahmatsyah, & Sani, R. A. (2021). Development of Dynamic Fluid props with ADDIE design at SMA. *Journal of Physics: Conference Series*, *1811*(1), 12069. Doi: 10.1088/1742-6596/1811/1/012069

[8]. Desnita, D., Raihanati, R., & Susanti, D. (2018). Smart Aquarium as Physics Learning Media for Renewable Energy. *IOP Conference Series: Materials Science and Engineering*, *335*(1), 12078. Doi: 10.1088/1757-899X/335/1/012078

[9]. Lengkong, M., Istiyono, E., Rampean, B. A. O., Tumanggor, A. M. R., & Nirmala, M. F. T. (2021). Development of Two-Tier Test Instruments to Detect Student's Physics Misconception. *Proceedings of the 7th International Conference on Research, Implementation, and Education of Mathematics and Sciences (ICRIEMS 2020)*, 561–566. Doi: 10.2991/assehr.k.210305.082

[10]. Motlhabane, A. (2016). Learner's alternative and misconceptions in physics: A phenomenographic study. *Journal of Baltic Science Education*, *15*(4), 424–440. Doi: 10.33225/jbse/16.15.424

[11]. Triyani, G., Danawan, A., Suyana, I., & Kaniawati, I. (2019). An investigation of students' misconceptions about momentum and impulse through interactive conceptual Instruction (ICI) with computer simulation. *Journal of Physics: Conference Series*, *1280*(5), 52008. Doi: 10.1088/1742-6596/1280/5/052008

[12]. Amalia, S. A., Suhendi, E., Kaniawati, I., Samsudin, A., Fratiwi, N. J., Hidayat, S. R., Zulfikar, A., Sholihat, F. N., Jubaedah, D. S., Setyadin, A. H., Purwanto, M. G., Muhaimin, M. H., Bhakti, S. S., & Afif, N. F. (2019). Diagnosis of Student's Misconception on Momentum and Impulse Trough Inquiry Learning with Computer Simulation (ILCS). *Journal of Physics: Conference Series*, *1204*(1), 12073. Doi: 10.1088/1742-6596/1204/1/012073

[13]. Azizahwati, A., Rahmad, M., & Zamri, R. (2021). Development of Digital Simple Pendulum Learning Media. *Journal of Physics: Conference Series*, *2049*(1), 12065. Doi: 10.1088/1742-6596/2049/1/012065

[14]. Irwandi, I., Sari, I. M., Oktavia, R., & Syukri, M. (2020). MEMS and IoT Applications in ISLE-based STEM Physics Learning Media for Mechanics Topic with LabVIEW Integration. *Journal of Physics: Conference Series*, *1462*(1), 12066. Doi: 10.1088/1742-6596/1462/1/012066

[15]. Çoban, A., & Erol, M. (2021). Teaching Impulse-Momentum Law by Arduino Based STEM Education Material. *The Physics Educator*, *3*(2), 2150006. Doi: 10.1142/S2661339521500062

[16]. Nieveen, N. (1999). Prototyping to Reach Product Quality. In J. van den Akker, R. M. Branch, K. Gustafson, N. Nieveen, & T. Plomp (Eds.), *Design Approaches and Tools in Education and Training*. Springer Netherlands. Doi: 10.1007/978-94-011-4255-7_10

[17]. Branch, R. M. (2009). *Instructional Design: The ADDIE Approach*. Springer New York. Doi: 10.1007/978-0-387-09506-6

[18]. Arifin, A. M., Pujiastuti, H., & Sudiana, R. (2020). Pengembangan media pembelajaran STEM dengan augmented reality untuk meningkatkan kemampuan spasial matematis siswa. *Jurnal Riset Pendidikan Matematika*, *7*(1), 59–73. Doi: 10.21831/jrpm.v7i1.32135

[19]. Zijlmans, E. A. O., Tijmstra, J., van der Ark, L. A., & Sijtsma, K. (2019). Item-Score Reliability as a Selection Tool in Test Construction. *Frontiers in Psychology*, *9*, 2298. Doi: 10.3389/fpsyg.2018.02298

[20]. Taber, K. S. (2018). The Use of Cronbach's Alpha When Developing and Reporting Research Instruments in Science Education. *Research in Science Education*, *48*(6), 1273–1296. Doi: 10.1007/s11165-016-9602-2

[21]. Aguilar-Marín, P., Chavez-Bacilio, M., & Jáuregui-Rosas, S. (2018). Using analog instruments in Tracker video-based experiments to understand the phenomena of electricity and magnetism in physics education. *European Journal of Physics*, *39*(3), 35204. Doi: 10.1088/1361-6404/aaa8f8

[22]. Serway, R. A., & Jewett, J. W. (2014). *Physics for Scientists and Engineers with Modern Physics* (9th ed.). Brooks/Cole Cengage Learning. Doi: 10.5860/choice.34-3910

[23]. Halliday, D., Walker, J., & Resnick, R. (2014). *Fundamental of Physics* (10th ed.). John Wiley.

[24]. Giancoli, D. (2013). *Physics: Principles with Applications* (7th ed.). Pearson.
[25]. Young, H. D., & Freedman, R. A. (2017). *University Physics with Modern Physics* (14th ed.). Pearson.
[26]. Kenfack, A., & Singh, K. P. (2010). Stochastic resonance in coupled underdamped bistable systems. *Physical Review E*, *82*(4), 46224. Doi: 10.1103/PhysRevE.82.046224
[27]. Cortés, J.-C., López-Navarro, E., Romero, J.-V., & Roselló, M.-D. (2021). Approximating the Density of Random Differential Equations with Weak Nonlinearities via Perturbation Techniques. In *Mathematics*, *9*(3), 204. Doi: 10.3390/math9030204
[28]. Leme, J. C., & Oliveira, A. (2017). Pendulum Underwater – An Approach for Quantifying Viscosity. *The Physics Teacher*, *55*(9), 555–557. Doi: 10.1119/1.5011833
[29]. Arya, A. P. (1997). *Introduction to Classical Mechanics* (2nd ed.). Pearson.
[30]. Wibowo, F. C., Maemunah, A. N., Nasbey, H., Costu, B., Prahani, B. K., Permana, N. D., Darman, D. R., & Samsudin, A. (2023). Development of simple kits (SK) refraction of light using photodiode sensors for student understanding. *EUREKA: Physics and Engineering*, *2*, 3–16. Doi: 10.21303/2461-4262.2023.002728
[31]. Kholiq, A., & Khoiriah, M. (2021). Online Learning During the Covid-19 Pandemic with ELISA Assistance on The Concept of Dynamic Fluid: Student Response Analysis. *Journal of Physics: Conference Series*, *1805*(1), 12042. Doi: 10.1088/1742-6596/1805/1/012042
[32]. Fan, M., & Cai, W. (2022). How does a creative learning environment foster student creativity? An examination on multiple explanatory mechanisms. *Current Psychology*, *41*(7), 4667–4676. Doi: 10.1007/s12144-020-00974-z
[33]. Çeken, B., & Taşkın, N. (2022). Multimedia learning principles in different learning environments: a systematic review. *Smart Learning Environments*, *9*(1), 19. Doi: 10.1186/s40561-022-00200-2