



Available online at <http://journal.walisongo.ac.id/index.php/jnsmr>

Design and build a mechanical energy conservation law KIT with Arduino microcontroller

Adina Widi Astuti¹, Zayyinul Mushthofa¹, Hartono², Sulhadi²

¹Postgradutae Program in Physics Education, Universitas Negeri Semarang, Indonesia

²Department of Physics Education, Universitas Negeri Semarang, Indonesia

Abstracts

Corresponding author:
adinawidi16@gmail.com
Received : 20 Oct 2021
Revised : 20 Nov 2021
Accepted : 1 Dec 2021

Tools as media play an important role in learning physics to explain concepts, so that students can more easily build mastery of physics material and develop their skills. This study aims to design and realize a physics learning tool. The method used is research and development (Research and Development). This learning tool is in the form of a plane where the direction of the object's trajectory varies can move up, down, and is accompanied by a slope setting (30°, 45°, 60° or 90°). Equipped with a speed output setting program based on 3 points whose speed will be measured and the distance between the points can be changed. Its function is to understand and prove the law of conservation of mechanical energy, understand the relationship between potential energy and kinetic energy experienced by objects and determine the speed of objects and their height position. This learning tool is expected to attract students' interest in learning physics. The design of this KIT Law of Conservation of Mechanical Energy can prove the conservation of mechanical energy. When an object is moving downwards, the object's height decreases but its velocity increases. On the other hand, if the object is moving upwards, the height of the object will increase, but the velocity of the object will decrease. This tool still has a relative error rate of 23.92% in free fall motion, 31.87% in falling motion on an inclined plane, and 32.79% in vertical upward motion.

©2021 JNSMR UIN Walisongo. All rights reserved.

Keywords: design; KIT; mechanical energy; Arduino microcontroller

1. Introduction

Natural Sciences (IPA) is part of human life, one of which is Physics. Physics is a science that studies natural behavior in various forms of

symptoms to be able to understand what controls or determines that behavior [5]. Physics in learning is developed through the ability to think analytically, inductively and deductively in solving problems related to the use of developing knowledge and skills [16].

Implementation of the learning process in schools, guidelines or methods to support the development of knowledge, skills, basic needs for delivering materials, concepts and physics information by educators, one of which is through the use of teaching aids [11]. The use of physics teaching aids is expected to make it easier for students to understand the concepts contained in physics material and learn an abstract concept to become more concrete or real [7], one of the studies of the Physics material is the load placed on an inclined plane with the classification of material namely the law of conservation Mechanical energy has previously been developed by Arimi [1], Energy and the Law of Momentum [8], Magnetic Field Strength [13], Law of Reflection of Light [14], Ohm's Law [12], Wave Speed [9], etc.

Based on data [6], the condition of the science laboratories of 8,886 public/private high schools has a science laboratory (joined) 26.20%, has a science laboratory (2 separate laboratories) 18.62%, has physics, biology and chemistry laboratories (3 separate laboratories) 24.18%, have a science laboratory 69% and do not have a science laboratory 31%. The condition of the IPA laboratory building is 41% good, 33% heavily damaged, 26% lightly damaged. The condition of the tools/materials is 27% complete and 73% incomplete. The use of science laboratories with a high frequency of 36%, moderate 31%, low 33%. Has 17.72% science laboratory assistant. The lack of learning tools or media that can provide a simple and real picture of the application of physics theory both at the high school and college level is the main problem in working on this design. Because of this condition, some teachers switch teaching aids to learning applications, such as in research [2], they develop applications for calculating mechanical energy. The use of the application is quite efficient but learning using teaching aids will be able to support learning, because it can be proven directly. This is in accordance with research [3], experimental learning with visual aids can improve the ability to understand the laws of mechanical energy. In addition, it can also improve the competence of teachers in utilizing the physics laboratory [15].

Experimental activities as a guide for students to develop skills are still minimal in some schools. Data from preliminary studies and observations made in 2 physics laboratories, namely SMA Islam Hidayatullah Semarang and SMA Negeri 1 Binangun Cilacap, they already have learning tools to support the law of conservation of mechanical energy. However, these teaching aids are still simple, and are still used manually by teachers and students.

Based on the development of learning tools that have been carried out by Palumpun [10], learning tools are used to prove the law of conservation of mechanical energy through objects placed on an inclined plane at a certain height and the time needed for objects to arrive from the object's position is still on top to the bottom. However, the tool is still manual so there are some obstacles in measuring time and there is the influence of the frictional force from the inclined plane base used.

Sumaningsih [17] has developed a learning tool to prove the law of conservation of mechanical energy using Gaius' media. This tool is designed using an inclined trajectory in the form of a parabola. Then the object is rolled from above to the end of the parabolic path to a flat path. Next is to measure the time and distance after passing the end of the parabolic trajectory. Students are asked to find velocity and prove it in the law of conservation of mechanical energy. This tool is still manual in measurement, it is very possible for errors to occur.

The next development is the physics teaching aid of the law of conservation of energy, force, velocity and acceleration on an inclined plane developed by Iryanto [6]. This tool consists of an inclined plane whose tilt angle can be adjusted from 0° to 90° , with various surface types and masses which will later be launched on an inclined plane to obtain physical parameters. This tool is equipped with a GUI (Graphical User Interface) that can display parameters of physical quantities in the form of raw data and graphs. The drawback of this tool is that there has not been a variation in the trajectory of objects in a vertical direction.

Based on this description, it is necessary to develop a learning tool for the law of conservation of mechanical energy on an inclined plane with varying trajectory directions, which can move up, down, and accompanied by tilt settings (30°, 45°, 60° or 90°). Equipped with a speed output setting program based on 3 points whose speed will be measured and the distance between the points can be varied. With the addition of a vertical upward trajectory that is more effective, practical and attractive but can be used automatically by students in practical activities at school. So it is hoped that students can see a real or concrete picture through a tool that can automatically be operated to describe the event of proving the law of conservation of mechanical energy. Through this learning tool, it is expected that students' abilities in understanding physics, especially the law of conservation of mechanical energy, can increase.

2. Experiments Procedure

The method used in this research is the research and development method. According to Borg and Gall [4] development research is a process that seeks to produce products that have faults in their development.

Development research comes from observing various symptoms that appear in the educational community that demand long-term handling of educational products. Development research directed at developing effective products for school purposes is an applied research. So this kind of research is more concerned with changes that bring improvement because this research not only examines general principles about educational theory but also examines what its uses are in education [5].

The product produced in this development research is the development of a learning tool for the law of conservation of mechanical energy on an inclined plane with a variable trajectory direction that the object can move up, down, and accompanied by tilt settings (30°, 45°, 60° or 90°). Equipped with a speed output setting program based on 3 points whose speed will be measured

and the distance between the points can be changed.

3. Result and Discussion

Preliminary Study Results

Preliminary study includes needs analysis and literature study that will help in knowing the constraints and needs of high school students and physics teachers in learning physics. Needs analysis in the form of questionnaires and Physics Teacher interviews. Questionnaire related to the views of Physics Teachers regarding the development of learning tools for the law of conservation of mechanical energy as a medium for learning physics on the subject of energy in class XI SMA.

The results of the preliminary study conducted at Islamic High School Hidayatullah Semarang and SMA N 1 Binangun Cilacap learning on the Law of Conservation of Mechanical Energy there is no tool that can prove quantitatively related to calculation analysis. So far, learning uses simulation, so students have not been able to directly prove or discover the concept of this material through practicum. In addition to laboratory observations, the literature review that has been published becomes a reference for the development of tools to be developed. Based on this preliminary study, researchers are trying to make a tool that can prove the Law of Conservation of Mechanical Energy in order to make it easier for teachers to teach the material.

Tool Design Stage

The learning tool for the law of conservation of mechanical energy (Figure 1) is adapted according to the provisions of the concept or material contained in the literature study book, which consists of the motion of objects in the direction of the upward, downward trajectory and with special angles (30°, 45°, 60° or 90°) with components of physical quantities such as velocity, altitude and mass. The track on this tool has a height of 80 cm,

so that the variation in height in this experiment can be changed as needed.

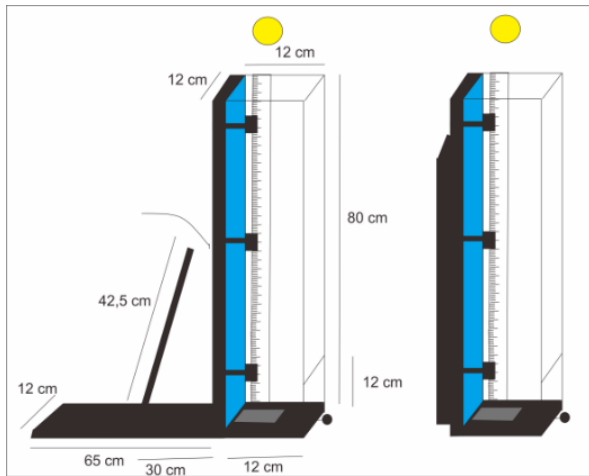


Figure 1. Mechanical Conservation Law KIT Design



Figure 2. Tilting Tool 45°

This learning tool (Figure 2) consists of a catapult that can throw objects up with a certain force and angle on a varied inclined plane. This launcher uses a spring that can be pulled with a rope. The length of the string being pulled indicates the magnitude of the force applied. This tool is equipped with an Arduino nano microcontroller and an infrared sensor that can measure the speed of objects at 3 different height points, then the output speed is displayed through the monitor. Each point being measured there are 2 infrared sensors with a distance of 0.5 cm, this is in order to measure the instantaneous speed at that point. On the monitor display there is a switch and a reset button. The switch is used to adjust the position of moving objects from above or below. While the reset button is used every time you start the experiment.



Figure 3. Sensor testing

The materials used in making the design consist of triplex and acrylic boards. Triplex is used as a support base and track when the tool is tilted. The triplex and the load used in this experiment have a smooth surface so that the resulting frictional force is small and can be neglected. The acrylic used looks transparent which covers the triplex board as a track, so that objects can be seen clearly. This acrylic serves as a load limiter so that it moves according to the trajectory and the sensor can detect objects correctly (Figure 3). This KIT is also equipped with a ruler to measure the height of the object we want to measure its instantaneous speed.

KIT Feasibility Trial Results

This experiment was carried out 3 times for each variation. Variations that can be done on the Law of Conservation of Mechanical Energy KIT are free fall motion, motion on an inclined plane and vertical upward motion as shown in Figure 5. The output data displayed on the monitor (Figure 4) will be compared with the theory of the law of conservation of mechanical energy.

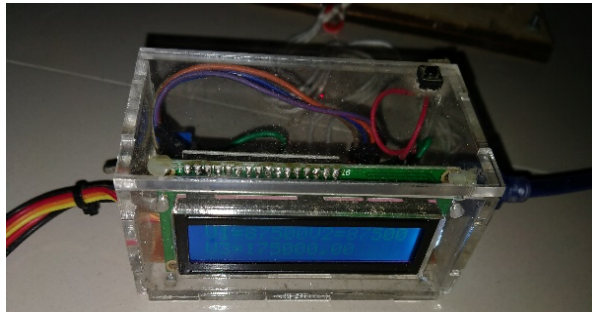


Figure 4. Display monitor

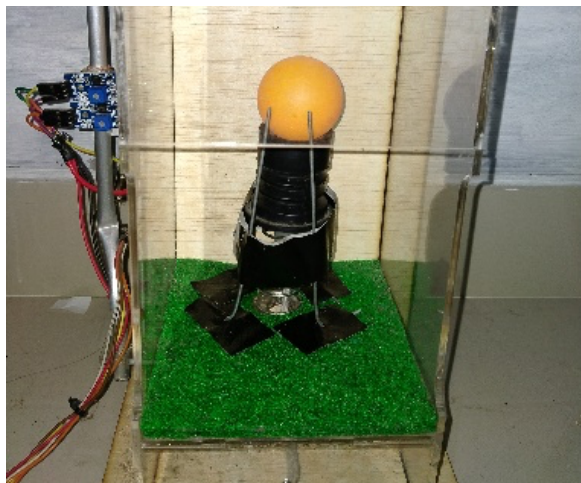


Figure 5. Upward motion test

How to use this tool begins by connecting the tool to an AC power source with a voltage of 5 volts. The power source can be a HP power bank or an HP charger adapter that is connected to AC power. Use objects with colors other than black so that they are easily detected by the sensor. Then measure the mass of the object being tested using a digital balance that has a high level of accuracy. Try to use the object that has a large mass so that friction in the air can be ignored. If you are experimenting with variations in vertical motion, use objects with a round shape so that the trajectory tends to be vertical. If the inclined plane experiment, use a box-shaped object to avoid rotational motion. The next step is to adjust the slope of the desired track. After that, measure the position of the sensor and the height of the object you want to drop, if the object is moved from below then pull the thrower as needed. Next we adjust the switch according to the position of the object. If the object moves from top to bottom, then the switch is positioned up, if the object moves from

bottom to top then the switch is positioned down. Then press the reset button every time you start the experiment. Wait for the monitor to turn on and the writing on the monitor flashes. The next step, remove the object and then observe the instantaneous speed displayed on the monitor. Finally, compare the measured data with the theory.

Free Fall Trial

The KIT Experiment of the Law of Conservation of Mechanical Energy for a free falling object uses a height of 75 cm, 47.5 cm and 20 cm. The weight used is 35 grams and is dropped at an initial height of 80 cm. The results of the data output displayed by the monitor display can be seen in the following table 1.

Table 1. Free fall test results

Massa m (gram)	Ketinggian h (cm)	Kecepatan v (cm/s)	Kecepatan rata-rata V _{rata-rata} (cm/s)
35	75	80,33	79,587
		82,55	
		75,88	
35	47,5	167,50	165,63
		141,90	
		187,50	
35	20	300,03	281,98
		268,12	
		277,80	

Mathematically the law of conservation of mechanical energy can be formulated as follows:

$$EM_1 = EM_2$$

$$EP_1 + EK_1 = EP_2 + EK_2$$

$$mgh_1 + \frac{1}{2}mv_1^2 = mgh_2 + \frac{1}{2}mv_2^2$$

So theoretically, the results of the analysis of the calculation of the free fall motion experiment can be seen in the following table 2.

Table 2. Analysis of the theoretical calculation of free fall motion

Massa m (kg)	Percepatan gravitasi g (m/s ²)	Ketinggian h (m)	Energi mekanik EM (J)	Energi potensial EP (J)	Energi kinetik EK (J)	Kecepatan v (m/s)
0,035	9,8	0,80	0,2744	0,2744	0	0
0,035	9,8	0,75	0,2744	0,25725	0,01715	0,989949
0,035	9,8	0,475	0,2744	0,16293	0,11148	2,523886
0,035	9,8	0,20	0,2744	0,0686	0,20580	3,429286

Based on Table 1 and Table 2, it can be seen that when using the KIT the Law of Conservation of Mechanical Energy, the speeds

at a height of 75 cm, 47.5 cm and 20 cm are 79.587 cm/s, 165.63 cm/s, and 281.98 cm/s respectively. If theoretically analyzed, an object with a mass of 35 grams dropped from a height of 80 cm without an initial velocity assuming an acceleration of 9.8 m/s² gravity has a velocity at a height of 75 cm, 47.5 cm and 20 cm, respectively, is 98.9949 cm/s, 252.3886 cm/s, and 342.9286 cm/s. From these data, the relative error of instantaneous speed on this tool for the height of h₁ is 19.60 %, h₂ is 34.38% and h₃ is 17.77% with an average relative error of 23.92%.

Experiment on an inclined plane

In this inclined plane experiment, it was carried out on a track with a slope of 45° with a weight of 35 grams moving from above. The heights are 59 cm, 40 cm and 19 cm. The output results on the monitor display can be seen in the following table 3.

Table 3. Test results of motion on an inclined plane

Massa m (gram)	Ketinggian h (cm)	Kecepatan v (cm/s)	Kecepatan rata-rata V _{rata-rata} (cm/s)
35	59	58,33	63,67
		45,17	
		87,50	
35	40	168,92	143,11
		112,60	
		147,80	
35	19	358,61	245,24
		167,30	
		209,80	

The results of the calculation analysis according to the law of conservation of mechanical energy can be seen in the following table 4.

Table 4. Analysis of the theoretical calculation of motion on an inclined plane

Massa m (kg)	Percepatan gravitasi g (m/s ²)	Ketinggian h (m)	Energi mekanik EM (J)	Energi potensial EP (J)	Energi kinetik EK (J)	Kecepatan v (m/s)
0,035	9,8	0,60	0,2058	0,20580	0	0
0,035	9,8	0,59	0,2058	0,20237	0,00343	0,442719
0,035	9,8	0,40	0,2058	0,13720	0,06860	1,979899
0,035	9,8	0,19	0,2058	0,06517	0,14063	2,834784

From Table 3 and Table 4 it can be concluded that the velocity of an object with a mass of 35 grams at a height of 59 cm, 40 cm and 19 cm is 63.67 cm/s, 143.11 cm/s, and 245.24 cm/s, respectively. In theory, an object dropped

from a height of 60 cm without an initial velocity assuming an acceleration of 9.8 m/s² gravity has a velocity at a height of 59 cm, 40 cm and 19 cm, respectively, is 44.2719 cm/s, 197.9899 cm/s, and 283.4784 cm/s. From these data, the relative error of the instantaneous speed of this tool for the height of h₁ is 43.82%, h₂ 38.35% and h₃ 13.49% with an average relative error of 31.87%.

Upward Vertical Motion Experiment

In the vertical upward motion experiment, the thrower is pulled by the same length of string. The results of the output data on the monitor can be seen in the following table 5.

Table 5. Test results of motion on an inclined plane

Massa m (gram)	Ketinggian h (cm)	Kecepatan v (cm/s)	Kecepatan rata-rata V _{rata-rata} (cm/s)
5	0	235,50	232,933
		217,60	
		245,70	
5	27,5	138,12	127,137
		99,26	
		144,03	
5	55	87,50	87,420
		87,26	
		87,50	

Testing of experimental data related to the law of conservation of mechanical energy for this experiment can be seen in the following table 6.

Table 6. Analysis of the theoretical calculation of motion on an inclined plane

Massa m (kg)	Percepatan gravitasi g (m/s ²)	Ketinggian h (m)	Kecepatan v (m/s)	Energi potensial EP (J)	Energi kinetik EK (J)	Energi mekanik EM (J)
0,005	9,8	0	2,32933	0	0,013564	0,01356445
0,005	9,8	0,275	0,189151	0,013475	0,000089	0,01356445
0,005	9,8	0,55	√-3,39422	0,02695	-0,008485	0,01356445

In the experiment of an object moving upwards which is the basis of the theory when the object is at a height of 0 cm, it has a speed of 232,933 cm / s. From the data in Tables 5 and 6, the mechanical energy will be searched as a basis for comparing experimental data and calculations. The mechanical energy produced by an object moving at a height of 0 cm is 0.01356445 J. Furthermore, this data is used to find the kinetic energy and instantaneous velocity at h₂ and h₃. The experimental data with a height of 27.5 cm and 55 cm have instantaneous speeds of 127.137 cm/s and

87.42 cm/s, respectively. However, the calculated data are 189,151 cm/s and cm/s. The relative error on h_2 is 32.79% while on h_3 it is clearly very different because it has an imaginary value. This upward motion experiment has not been able to prove the law of conservation of mechanical energy properly.

KIT The Law of Conservation of Mechanical Energy can prove the concept of conservation of mechanical energy. When an object is free falling or moving downward on an inclined path, the object's height decreases but the object's speed increases. Conversely, when an object moves up either vertically or on an inclined plane, the height of the object increases but the object's speed decreases, even though the vertical motion upwards is still far different from the theory of the law of conservation of mechanical energy.

This experiment using the Law of Conservation of Mechanical Energy KIT still has a relative error rate. This is because there are several factors that affect the experiment, namely: (1) air friction and board friction on an inclined plane cannot be ignored. In the experiment of free fall motion and vertical upward motion, horizontal air friction can be eliminated due to the presence of acrylic, but vertical air friction cannot be ignored. On an inclined plane, even though the board is made so smooth, there is still friction between the board and the object; (2) parallax error in measuring the height of the sensor or object when it is dropped. Due to a small shift in the sensor can cause the instantaneous speed measurement results to also change; (3) small objects have a small air friction force but allow objects to be difficult to detect by the sensor; and (4) when moving vertically upwards, objects sometimes move on an inclined trajectory so that the sensor cannot detect objects.

4. Conclusion

The design of this KIT Law of Conservation of Mechanical Energy can prove the conservation of mechanical energy. When an object is moving downwards, the object's height decreases but its velocity increases. On the other hand, if the object is moving upwards, the height

of the object will increase, but the velocity of the object will decrease. This tool still has a relative error rate of 23.92% in free fall motion, 31.87% in falling motion on an inclined plane, and 32.79% in vertical upward motion. This error makes the amount of potential and mechanical energy experience an error as well so that the conservation value of mechanical energy cannot be the same at every point of the experiment. This is because it is influenced by several factors, namely: the friction of the air and the board; parallax error when measuring the height of the sensor; the sensor is difficult to detect small objects; and the thrower can't make things move straight up well.

Acknowledgment

The authors gratefully acknowledge the use of service and facilities at Universitas Negeri Semarang.

References

- [1] Arimi, N. I., Iswanto, B. H. dan Susila, A. B. 2019. Set Praktikum Energi Mekanik untuk Pembelajaran Hukum Kekekalan Energi Mekanik di SMA. *Seminar Nasional Pendidikan Fisika dan Pembelajarannya*, Universitas Negeri Malang: 100-104.
- [2] Ariwibowo, D. dan Desmira. 2016. Pengembangan Aplikasi Simulasi Perhirungan Energi Mekanik Berdasarkan Hukum Kekekalan Energi dalam Proses Belajar Siswa. *Jurnal PROSISKO*. 3 (1) : 12-16
- [3] Barata, Bima. 2016. Penggunaan Metode Eksperimen untuk Meningkatkan Kemampuan Memahami Hukum Kekekalan Energi Mekanik pada Siswa Kelas II Semester I SMA NEGERI 1 Bendungan Kabupaten Trenggalek Tahun Ajaran 2010/2011. *Jurnal Inspirasi Pendidikan*. 6 (1) : 792-801
- [4] Borg, W.R. dan Gall, M.D. 1983. *Educational Research An Introduction*. New York: Longman.
- [5] Desy, Desnita, Raihanati. 2015. Pengembangan Alat Peraga Fisika Materi Gerak Melingkar untuk SMA. *Prosiding*

- Seminar Nasional Fisika (E-Journal)*. 4(10): 39-44. Miring. Skripsi. Program Studi Teknik Elektro, Universitas Kristen Satya Wacana.
- [6] Iryanto, Hendika. 2015. Alat Peraga Fisika Hukum Kekekalan Energi, Gaya, Kecepatan dan Percepatan pada Bidang Pendidikan IPA (JPPIPA). 6(1) : 40-44
- [7] Kustandi. 2013. *Media Pembelajaran*. Bogor: Ghalia Indonesia.
- [8] Mudhofir, F., Effendy, S. Linuwih, S. dan Sulhadi. 2019. Infrared Sensor Kit as a Speed Detector in the Practicum of Energy and Momentum Laws. *Journal of Innovative Science Education*. 8 (1): 55-60.
- [9] Octaviani, L. A., Prastowo, S. H. B., Anggraeni, F. K. A. 2021. Desain Rancang Bangun Trainer Kit untuk Menentukan Pengaruh Jenis Bahan Tali terhadap Cepat Rambat Gelombang. *Jurnal Inovasi Pendidikan Fisika dan Riset Ilmiah*. 5 (1): 33-42
- [10] Palumpun, Normalia Sandy. 2019. Meningkatkan Pemahaman dan Kemandirian Belajar Siswa Kelas X SMA Negeri 6 Yogyakarta pada Materi Hukum Kekekalan Energi Mekanik pada Bidang Miring Menggunakan Metode Eksperimen Terbimbing. *Skripsi*. Program Studi Pendidikan Fisika, Universitas Sanata Dharma.
- [11] Pramudyawan, M. T. S., Aris Doyan, Jannatin A. 2020. Pengaruh Model Pembelajaran Inkuiri Terbimbing Berbantuan Kit Alat Percobaan Usaha dan Energi terhadap Penguasaan Konsep Fisika Peserta didik. *Jurnal Penelitian*
- [12] Pratama, F. R., Sasmiko, A. H. (2021). Pengembangan Buku Ajar Simulasi dan Pemodelan Fisika dengan Unity3D Berbasis Self Regulated Learning. *Physics Education Research Journal*. 3 (2): 95-102.
- [13] Rahmawati, Ana Silfiani. (2019). Penggunaan Multimedia Interaktif (MMI) sebagai Media Pembelajaran dalam Meningkatkan Prestasi Belajar Fisika. *Pancasakti Science Education Journal*. 4 (1).
- [14] Rizqi, Muhammad., Yulianawati, Dewi., Nurjali. (2020). Efektifitas Model Pembelajaran Problem Based Learning Terhadap Kemampuan Pemahaman Konsep Fisika Siswa. *Jurnal Pendidikan Fisika dan Sains*. 3 (2); 43-47.
- [15] Saefullah, A., Fakhturrokhman, M., Oktarisa, Y., Arsy, R. D., Rosdiana, H., Gustiono, Indriyanto, S. 2018. Rancang Bangun Alat Praktikum Hukum Ohm Untuk Memfasilitasi Kemampuan Berfikir Tingkat Tinggi (Higher Order Thinking Skills). *Jurnal Gravity*. 4 (2): 81-90.
- [16] Safari, I., Putri, I. A., Purbosari, R., Huljannah, R. A., Sugihartono, I., Marpaung, M. A. 2019. Rancang Bangun Eksperimen Sederhana Kuat Medan Magnet Menggunakan Sensor Kecepatan Arduino. *Prosiding Seminar Nasional Fisika*. Universitas Negeri Jakarta: 247-254.
- [17] Santoso, P. H. 2020. Rancang Bangun Alat Ukur Jarak Antara Dua Titik dengan Menerapkan Hukum Pemantulan Cahaya. *Jurnal Inovasi dan Pembelajaran Fisika*. 7 (1): 90-99.
- [18] Sulhadi, Teguh Darsono, Siti Wahyuni dan Yeni Rima Liana. 2020. Optimalisasi Perancangan Alat Peraga untuk Meningkatkan Kompetensi Guru dalam Pemanfaatan Laboratorium Fisika. *Seminar Nasional Pascasarjana*. Universitas Negeri Semarang: 111-117.
- [19] Sumaji. 1998. *Pendidikan SAINS yang Humanistik*. Jakarta: Kanisius.
- [20] Sumaningsih, Ni Made Ayu. 2019. Meningkatkan Kemampuan Menerapkan Hukum Kekekalan Energi Mekanik Menggunakan Media Gayus di Kelas VIII. 6 SMP N 1 Tanjung. *Jurnal Kependidikan*. 5 (1) : 40-46.