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Development and Validation of Free Fall Motion Experiment Kit Based on Arduino UNO and Phyphox Application

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Abstract: This study aims to develop and validate science teachers' perception of the free fall motion practicum device based on Arduino UNO and the Phyphox Application through the Science Subject Teachers' Deliberation (MGMP) forum. This research method applies the research and development (RnD) method with the ADDIE (Analysis, Design, Development, Implementation, Evaluation) model. The first step is the analysis of the needs of the problem of misconceptions of free fall motion and the selection of media to be developed; the second step is the design of the development of the device used, namely Arduino UNO and the Phyphox Application in the form of a digital sketch before continuing to the development process. The third step is the development of the Arduino UNO and Phyphox free fall motion kit prototype; the fourth step is the implementation of a data collection trial carried out by a group of volunteer students in the free fall motion practicum and continued with the introduction of the device through the MGMP Science forum. The final evaluation activity is the collection of data from the science teacher perception questionnaire on the developed tool and validating the tool. The results of the testing and development show that Adruino has a slightly lower accuracy level than the phyphox application. These results were obtained from practical activities by a group of students. This may be influenced by development factors and technical settings that can affect the accuracy level of the Adruino practical tool. Each tool has its advantages; Adruino is suitable for training students in coding programming and technology-based learning according to the needs of the 21st century. Meanwhile, Phyphox offers practicality and fast and efficient use. Through practicality testing, both tools provide good and relevant results to improve the quality of learning, especially in the misconception of free fall motion.

Keywords: free fall motion, arduino UNO, phyphox application.

▪ INTRODUCTION

Free fall is a physical phenomenon often encountered in everyday life, such as the fall of a ball or other object at a certain height. This phenomenon is a fundamental concept in basic physics material at the junior high school level (SMP/MTS), which is the main foundation in studying the material on motion and the interactions of objects that occur, as well as the forces that influence (mechanics) and the law of gravity. This concept teaches that every object that falls will go to the centre of the earth with gravitational acceleration (g) (Rafika & Syuhendri, 2021; Sianoudis et al., n.d.).

As is known, studying this phenomenon requires a strong foundation of mature conceptual understanding so that the following concept can be learned well without any obstacles. The idea relates to concepts such as Newton's laws, momentum, kinetic and potential energy and other phenomena.

Although the concept of free fall motion is part of everyday life that they often encounter, in some cases, misconceptions that continue to develop around students' lives still frequently occur. One of the popular misconceptions that arise in students related to learning this concept is that they assume that objects with a large mass, when compared

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to light mass, when dropped at the same height, then objects with a larger mass will hit the ground faster than objects with a light mass (Körhasan, 2021; Sari et al., 2019).

Misconceptions like this are a challenge for educators to be able to teach physics concepts properly and correctly. The tendency of students to rely on everyday experiences that occur in students without involving and considering scientific explanations causes students' understanding of the concept to be less appropriate and less (Körhasan, 2021; Sari et al., 2019). Therefore, as educators, we should consider that a more practical approach is needed in the learning process, such as involving direct experimental activities to help students understand the concept of free fall motion, which is aligned with theory..

One of the common efforts made by teachers in teaching free fall motion material is by conducting simple experiments through practical activities using a stopwatch. However, this effort certainly has weaknesses in data accuracy and measurement timeliness, which significantly impact less-than-optimal measurement results in conveying the actual concept of gravitational acceleration. Therefore, using technology-based aids is an alternative solution that can provide students with direct experience in understanding the concept of free fall motion better and more accurately in data collection.

In this era of rapid technological development, it is only right that the learning process involves the results of the development of experimental devices that utilize technology as a teaching aid. Using technology developed as a teaching aid is undoubtedly an innovative and creative solution carried out by teachers to help students eliminate misconceptions. Cai et al., (2021); Yildiz & Guler Yildiz, (2021) By involving the development of technological results in practical activities, it can provide better teaching in critical thinking and accordance with the development of multidimensional 21st-century skills and increase student efficacy in the learning process..

Some studies, such as Suzen & Kayaalp, (2019); Walid & Umar, (2022) The use of proximity sensors with the help of Arduino UNO microcontrollers and built-in smartphone sensors with the Phyphox application software are alternatives in free fall motion practicum activities with the help of technology. Both technologies utilize sensors to record the start-to-end time automatically and in real time. However, the two technologies have fundamental differences. On Arduino UNO, it is necessary to assemble the device, from installing the sensor to the microcontroller to installing the coding program to run the device. Meanwhile, the Phyphox application is software that can be used directly from a smartphone without assembly.

Based on the previous study, the researcher offers an update on the research gap that has not been done by previous researchers related to the comparison of the use of the Arduino UNO microcontroller and the Phyphox Application in terms of data accuracy when conducting free fall motion practicum activities and the practicality of using the tool in the learning process according to the perception of science teachers who can later evaluate the advantages and limitations of using the Arduino UNO microcontroller and the Phyphox Application in free fall motion practicums.

Through the explanation above of the research activities that the author has carried out, this activity aims to develop a free-fall motion experiment tool using a modern technology base based on the needs of the 21st century. In addition to the development of tools for free fall motion practicums, another goal of the researcher is to validate science teachers regarding their perceptions of the introduction of the media in science learning through the Science Subject Teacher Deliberation (MGMP) forum before being applied to their respective schools to determine the level of effectiveness of use. Through the involvement of teachers in the validation process, it is hoped that the developed free-fall motion practicum media will be able to meet the needs of learning in the field. Finally, this research will contribute to users' development of practicum media as a strategy in the innovative physics teaching process.

▪ METHOD

Participsnts

The sample in this study amounted to 30 respondents, comprising 15 education students who will conduct free fall motion practicums in implementation activities to test the developed tools and 15 MTs science teachers, who were randomly selected through the Science Subject Teachers' Deliberation (MGMP) activities. The 15 education students were grouped into three groups, and each group took free fall motion data at different heights. Group A took data at a height of 0.8 meters, group B 1 meter and group C 1.4 meters. Furthermore, 15 science teachers were selected purposively through the MGMP forum to find out the perception and potential of the developed practicum tools.

Research Procedures and Research Activities

This research uses a development method adopted from the ADDIE development model (Analysis, Design, Development, Implementation and Evaluation) (Sugiyono, 2017). Where the developed product is tested on small groups, both by students and the response of science subject teachers, to determine the level of validation, both from the level of usability and practicality in the process of learning Physics in the material of free fall motion. In detail, the following activities carried out in this research process are presented in table 1 below:

Table 1. Activities activities in the ADDIE model

Model ADDIE	Aktifitas
Analysis	• Analysis of educators' needs related to students' understanding and misconceptions regarding the phenomenon of free fall motion.
Design	• Determination of the design of the free fall motion practical kit • Simple practical kit design based on Arduino UNO and Phyphox in sketch form
Development	• Development of a prototype free fall motion practical kit based on Arduino UNO and Phyphox applications • Development of data collection instruments for both student samples in the implementation of experiments and feedback from science teachers in the MGMP forum.
Implementation	• Implementation of the use of a free fall motion practical kit based on Arduino UNO and the phyphox application to a small sample of 15 education students.
Evaluation	• Evaluation of prototype feedback through the MGMP IPA forum in Banyumas Regency

Instruments

The data collection instruments in this study consist of two main types: the first instrument is the results of practicums carried out by student groups. The data collected are in the form of measurement results. Meanwhile, the second instrument is a questionnaire given to science teachers. This questionnaire includes ease of use, development potential in each school and the usefulness of using the media. Through this questionnaire, researchers can evaluate the practicum Kit to be applied on a wider scale later in the learning environment in science lectures. The following are details of the instruments used.

Table 2. Research instruments and research data

Research Instruments	Data collected	Objective
Results of each group's practical work (group report)	• Data measurement results • Practical process notes	• Testing the effectiveness of the Practical Kit in small groups (practical report analysis)
Science Teacher Evaluation Questionnaire	• Teachers' perceptions regarding ease of use	• Assessment of perception and potential use of Practical Kits for science teachers

Data Analysis

The collected data, both from the report data in small groups related to free fall motion experiments using the developed tools, were then analyzed to determine the effects of using the developed tools. The analysis used consisted of descriptive analysis related to practicum notes and reflections from teachers regarding the perception of the development of the Arduino UNO practicum tool and the Phyphox Application. In addition to the analysis carried out using the descriptive method, data analysis was also carried out using the equation:

$$p = \frac{x}{\sum x} x 100\% \qquad (1)$$

Next, the researcher categorized the results obtained from the equation above to be interpreted, the following is a categorization to determine the perception response from the equation. The percentage category obtained through the questionnaire instrument distributed to science teachers in the MGMP forum is their perception of the developed practicum kit. This category is divided into four levels, namely "very practical" with a range of 76% to 100%; "practical" with a range of 51% to 75%; "quite practical" with a range of 26% to 50%; and "not practical" with a range of 0% to 25%. This category was adopted from previous researchers (Kurniawan et al., 2023) which is used as a form of the results of the teacher's perception description in validating the free fall motion kit

▪ RESULT AND DISSCUSSION

Anaysis

Free fall motion material is basic material in understanding kinematics and dynamics. However, based on the results of observations in the lecture process and in observations of learning in elementary school students, a serious problem was still found regarding the understanding of the concept of free fall motion, and previous research revealed that there are still many misconceptions such as (Eviota & Liangco, 2024; Khoirunnisa et al., 2024; Nisa & Habibbulloh, 2024). Factors that trigger misconceptions include a lack of understanding of the material, abstract explanations without the support of simulation visualizations and simple practicums without involving the use of technology in the data collection process.

Through the analysis of the problem, it is necessary to design a simple free fall motion demonstration tool that utilizes technology so that it can provide a comprehensive understanding both theoretically and practically with the hope of strengthening the quality of physics learning, especially in the free fall motion material. Some references (Firdaus et al., 2024; Indrasari et al., 2021) has discussed the use of technology such as the use of Arduino Uno to help the learning process in physics material, in addition to other researchers from (Radu et al., 2022; Walid & Umar, 2022; Zdeshchyts & Zdeshchyts, 2023) providing the presence of the phyphox application which can be downloaded on the Playstore also provides convenience in the process of taking free fall motion data based on smartphones.

Some previous studies, although they have presented free fall physics learning using technology, have not found any research that specifically provides a comparison between the use of Arduino Uno and the Phyphox Application in physics learning. Through this study, researchers provide new space for the development of technology in education about the advantages and limitations between Arduino UNO and the Phyphox Application, and provide solutions to educators who experience similar things about misconceptions of free fall motion that occur in students.

Design

Next, after analyzing the needs for tool development, the second stage of the ADDIE process is carried out, namely Design. In accordance with the needs at the analysis stage, the design for developing the Arduino UNO tool and the use of the phyphox application in the practicum activities that will be used later. The following is a sketch of the design in digital form before being developed into a prototype tool that is carried out

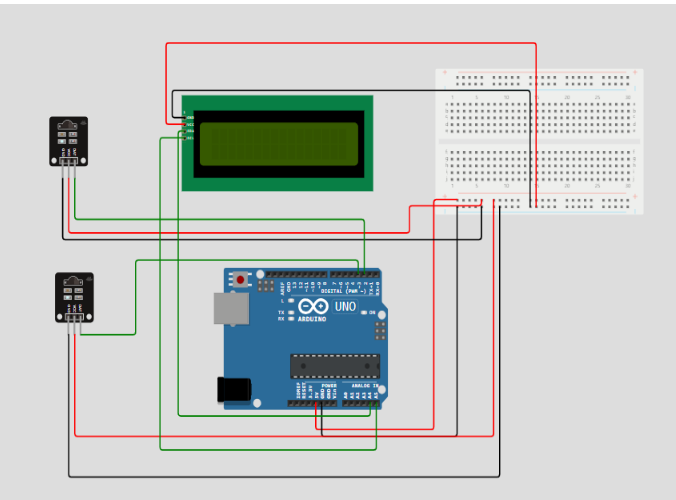


Figure 1. Free fall motion kit development sketch with adruino

Figure 2. Development sketch of free fall motion kit

Development

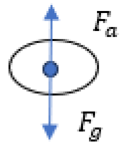
The development carried out is a further step from the efforts to realize the previously designed sketch design. This development process is an effort to adjust the materials and tools needed and refine the previously made design sketch. The results of this development are expected to be practical, effective and easy to apply. The following is a picture of the kit development.

Figure 3. Free fall motion kit adruino and phyphox application

Implementation

The fourth stage is the implementation of the prototype when used, in this case, the free fall motion practicum carried out by education students. However, before the practicum is carried out, students need to know the theory of free fall motion and the theory of free fall motion so that students can later calculate the gravitational acceleration obtained with the theory of gravity in the practicum..

When an object is dropped from a certain height, the force acting on the system is the gravitational force or weight force. F_g) where the object will tend to be pulled down to the earth (down). In addition, the object will also experience a slave force F_a) (up). Here is the illustration. Basic Equation: For free fall motion, use the equation based on Newton's second law.



Where :

$$F_a = \frac{C_d \rho A v^2}{2} \quad (1)$$

$$F_g = m.g \quad (2)$$

$$\sum F = m.a \quad (3)$$

$$F_a - F_g = m.a \quad (4)$$

$$\frac{C_d \rho A v^2}{2} - m.g = m.a \quad (5)$$

$$\frac{C_d \rho A v^2}{2} - g = a \quad (6)$$

$$\frac{C_d \rho A v^2}{2} - g = \frac{dv}{dt} = \frac{d^2 y}{dt^2} \quad (7)$$

Because the value of air resistance is very small, equation 7 can be rewritten as

$$\frac{dv}{dt} = g \quad (8)$$

Next, the equation is integrated into

$$\int dv = \int g\, dt \quad (9)$$

Then it is obtained:

$$v(t) = g.t + v_0 \quad (10)$$

Equation 10 is reintegrated to become the equation for the position y(t)

$$y(t) = \frac{1}{2} g t^2 + v_0 t + y_0 \quad (11)$$

Through equation 11, if the object is considered to be at rest (v_0=0) and ($y_0 = h$) then equation 11 can be simplified to

$$0 = h - \frac{1}{2} g t^2 \quad (12)$$

So to find the equation of gravity, namely:

$$\frac{1}{2} g t^2 = h \quad (13)$$

$$g = \frac{2h}{t^2} \quad (14)$$

Through the final result of equation 14, the free fall motion experiment can be done to calculate the acceleration of gravity. The experiment was carried out by considering ideal conditions that can be controlled, such as a room that is not affected by wind speed, which can reduce external variability. The following are the results of the experiment carried out using Arduino and phyphox

Table 3. Experimental data using Arduino

	h (m)	Massa A (150 gr)				Massa B (250 gr)			
		t (s)	v (m/s)	g (m/s^2)	Average Gravity	v (m/s)	v (m/s)	g (m/s^2)	Average Gravity
Group A Data	0.8	0.41	4.02	9.52	10.44	0.4	4.00	10.00	10.22
		0.39	3.83	10.52		0.39	4.10	10.52	
		0.38	3.73	11.08		0.41	3.90	9.52	
		0.4	3.92	10.00		0.4	4.00	10.00	
		0.38	3.73	11.08		0.38	4.21	11.08	
Group B Data	1	0.44	4.55	10.33	10.16	0.45	4.44	9.88	9.62
		0.44	4.55	10.33		0.46	4.35	9.45	
		0.43	4.65	10.82		0.46	4.35	9.45	
		0.45	4.44	9.88		0.46	4.35	9.45	
		0.46	4.35	9.45		0.45	4.44	9.88	
Group C Data	1.4	0.53	5.28	9.97	9.97	0.51	5.49	10.77	10.28
		0.52	5.38	10.36		0.52	5.38	10.36	
		0.53	5.28	9.97		0.53	5.28	9.97	
		0.53	5.28	9.97		0.52	5.38	10.36	
		0.54	5.19	9.60		0.53	5.28	9.97	

Table 4 Experimental data using phyphox application

	h (m)	Massa A (150 gr)				Massa B (250 gr)			
		t (s)	v (m/s)	g (m/s^2)	Average Gravity	t (s)	v (m/s)	g (m/s^2)	Average Gravity
Group A Data	0.8	0.403	4.02	9.85	9.95	0.401	3.99	9.95	9.98
		0.398	3.83	10.1		0.396	4.04	10.2	
		0.401	3.73	9.95		0.404	3.96	9.8	
		0.404	3.92	9.8		0.401	3.99	9.95	
		0.399	3.73	10.05		0.4	4	10	
Group B Data	1	0.448	4.55	9.96	9.96	0.451	4.43	9.83	9.83
		0.445	4.55	10.1		0.449	4.45	9.92	
		0.449	4.65	9.92		0.449	4.45	9.92	
		0.45	4.44	9.88		0.452	4.42	9.79	
		0.449	4.35	9.92		0.454	4.41	9.7	
Group C Data	1.4	0.529	5.29	10.01	9.92	0.532	5.26	9.89	9.93
		0.532	5.26	9.89		0.53	5.28	9.97	
		0.531	5.27	9.93		0.531	5.27	9.93	
		0.531	5.27	9.93		0.531	5.27	9.93	
		0.534	5.24	9.82		0.531	5.27	9.93	

Tables 3 and 4 confirm that the calculation of gravitational acceleration produced through the development of a free fall motion kit using the Adruino and Phyphox applications provides accuracy that is almost similar to the theoretical value of gravity, namely 9.8 m/s2 or 10 m/s2. The resulting difference can be said to be very minimal by approaching the standard value so that both measuring instruments on Arduino and phyphox have quite a good accuracy (Coramik & İnanç, 2023; Šiška et al., 2024). However, when viewed in terms of the gravity value successfully obtained, the phyphox application shows an accuracy approaching the standard value of the law of gravity compared to the use of Arduino.

In essence, the Arduino sensor is an electronic device that detects or measures physical changes that occur in the surrounding. Where the use of sensors on the Arduino changes physical parameters into electrical signals, which are then read by the Arduino to be processed more deeply through the coding program that has been applied environment (Adebola Olayinka et al., 2021; Coban & Coban, 2020). Meanwhile, the phyphox application is a practical mobile application that utilizes sensors on smartphones (HP), such as in this free fall motion experiment using a microphone as a time recording sensor between the two sounds produced when the object is first dropped until it touches the ground (Carroll & Lincoln, 2020; Walid & Umar, 2022).

Both Adruino and Phyphox have their own advantages depending on the experimental needs required. Adruino provides the possibility for users to design and customize experimental tools according to user needs, while Phyphox is more about fast, practical measurements in simple and portable experiments that can be done anytime without being tied to advanced programming.

So, the final conclusion of this experimental data is that the phyphox application shows advantages in various aspects compared to Arduino. The accuracy of the phyphox application in calculating the gravity value from the experiments carried out on both changes in height and the objects used shows more data consistency compared to the proximity sensor in the use of Arduino. In addition, in terms of practicality in assembling this free fall motion experiment tool, the use of the phyphox application does not require complicated configurations, such as in the development of tools in Arduino

Evaluation

The final stage of this research process is product evaluation, where product assessment is carried out by several science teachers who are directly involved in the free fall motion learning process. Several points that are evaluated are related to usefulness, effectiveness and practicality. The following are the evaluation results that we have successfully obtained through the distribution of questionnaires

Table 5. Teacher's perception on the development of the kit

No	Respondent	Percentage		
		Usefulness	**Effectiveness**	**Practicality**
1	A	90	90	80
2	B	95	90	95
3	C	95	75	70
4	D	95	90	80
5	E	95	80	85
6	F	90	85	85
7	G	85	90	80
8	H	85	85	90
9	I	85	75	80
10	J	95	85	95
11	K	90	85	85
12	L	90	90	80

13	M	75	80	100
14	N	85	70	80
15	O	90	95	90
Total		1340	1265	1275
Percentage		89.333	84.333	85

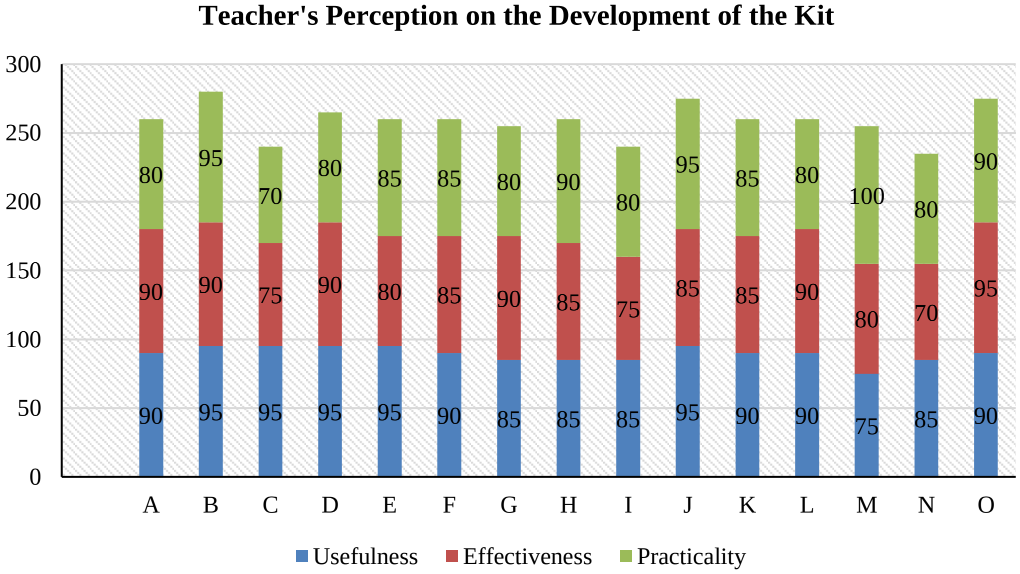


Figure 5. Percentage teacher's perception on the development of the kit

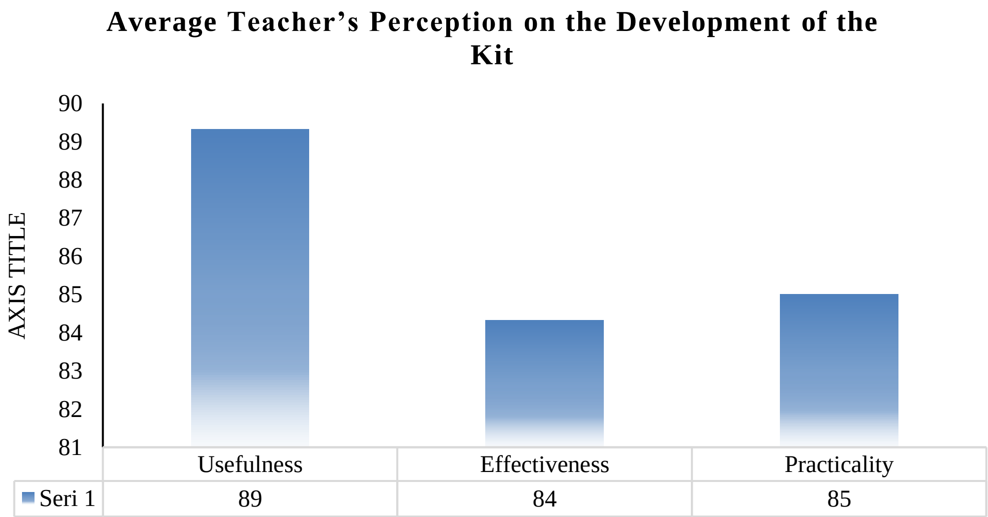


Figure 6. Average percentage teacher's perception on the development of the kit

Through the results obtained on teacher perceptions related to the development of experimental tools, it was found that the scores for the average usefulness, effectiveness and practicality of the 12 statements given were obtained with each percentage score of 89% for usefulness, 84% for effectiveness and 85% for practicality. Overall, the evaluation results related to science teacher perceptions of the development of Adruino-based practical tools and the phyphox application have great potential to be applied to the learning process, especially in the free fall motion material and provide material in-depth to students. These results can provide an indication that the development of a free fall motion practical kit based on Arduino and the phyphox application is able to support physics experiments in schools to help deepen the free fall motion material (Indrasari et al., 2021; Šiška et al., 2024; Walid & Umar, 2022).

In addition, product evaluation is assessed from teachers' perceptions of the results of media development. Researchers also conducted an effectiveness test on the cognitive outcomes of 15 students in small groups after performing the following practicum results from the pretest and posttest of 15 students.

Table 6. Pretest and posttest score 15 students college

No.	Code	Score		Ngain
		Pretest	Posttest	
1	M1	48	77	0.55
2	M2	42	80	0.65
3	M3	59	80	0.51
4	M4	47	78	0.58
5	M5	47	67	0.37
6	M6	38	63	0.4
7	M7	55	73	0.4
8	M8	33	64	0.46
9	M9	49	63	0.27
10	M19	55	71	0.35
11	M11	49	74	0.49
12	M12	64	70	0.16
13	M13	48	83	0.67
14	M14	48	70	0.42
15	M15	60	73	0.325
Average				044

By calculating the Ngains value obtained from a small group of students after the practicum, the Ngains value was obtained with an average of 0.44. If confirmed through the criteria table from Hake, (1998) Ngains value between 0.3 to 0.7 then it can be categorized as moderate. So it can be concluded in the development of experimental kits based on Arduino UNO and Phyphox Application has a fairly good level of effectiveness in improving student learning outcomes in free fall motion material.

▪ CONCLUSION

The development of free fall motion practicum kits using both Arduino and phyphox applications provides innovative technology-based solutions in proving free fall motion. Both of these practicum kits have their own advantages, with Adruino providing a coding and technology-based learning experience. At the same time, the phyphox application offers practicality in compiling practicum kits. Both of these kits, through assessments from science teachers, are able to provide great potential for improving the quality of learning in schools

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