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Development of Arduino Uno-Based Doppler Effect Trainer with FC-04 Sensor and HCSR-04 Sensor in Senior High School

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ABSTRACT.
Students' understanding of learning materials will increase with the presence of teaching aids. This study aims to produce a product in the form of a Doppler effect demonstrator based on Arduino Uno with FC-04 and HC-SR04 sensors in high schools, as well as to assess the feasibility of the developed teaching aids and determine students' responses to the developed teaching aids. This research is a type of development research (R&D) using the ADDIE development model. The research subjects consist of 2 physics education lecturers as media expert validators, 1 teacher at one of the high schools in Kota Bengkulu as a material expert validator, and 65 students from12th grade Science at one of the high schools in Bengkulu City. The research instruments used were needs analysis sheets, material expert and media expert validation sheets, and student response sheets. Data collection was carried out through questionnaires distributed to the validators and students. The results of media and material validation tests obtained average scores of 85% each, categorized as very feasible. Based on these results, it can be concluded that the Doppler effect practical demonstrator using FC-04 sensor and Arduino Uno is feasible. As for the student response results, the average score obtained was 85%, categorized as very good.

INTRODUCTION

Education is inseparable and essential in human life because it can create individuals with better qualities (Charli et al., 2019). As a branch of science, physics focuses on understanding facts, natural phenomena, thoughts, and experimental results. In physics learning, the focus is on non-living objects, natural phenomena, and interrelated events; this results in abstract concepts that are often difficult for students to understand (Rizaldi et al., 2020; Melawati et al., 2019). Media is one component of the learning system. Understanding physics principles requires a deep understanding that can help students achieve more comprehensive knowledge. The use of learning media can facilitate data interpretation and summarize information. Compared to conventional methods involving teacher lectures, students learning through media tend to be more excited and interested in their learning process (Wahyuningsih et al., 2019).

One way to teach physics subjects is through teaching aids as a learning medium. Physics props visually illustrate concepts that may be difficult or cannot be immediately seen by students (Rahmani et al., 2022; Maryam & Fahrudin, 2020; Cahyo et al., 2019). Teaching aids are learning tools that reflect and embody the concepts' characteristics. Teaching aids are essential in presenting messages and information about physics subjects teachers teach (Kause, 2019).

Wave material is one of the abstract materials in physics learning because it can only be known from references without directly seeing the wave's absolute motion (Octaviani et al., 2021). One phenomenon that is often considered abstract is sound waves. Sound waves cannot be seen directly by the human eye but can only be heard. The Doppler effect is an example of the phenomenon most often encountered in sound waves. Students often need help understanding the concept of the Doppler effect because it is difficult to conceptualize. Therefore, it is necessary to develop physics teaching aids for the Doppler effect phenomenon to help students understand the influence of each magnitude on the Doppler effect phenomenon as a practicum medium in schools (Widaningrum, 2021).

The trials on student learning motivation and understanding of concepts using motivation questionnaires showed moderate category results with a pretty good percentage to increase student learning motivation. In addition, there are also medium category results with a perfect percentage in improving students' understanding of concepts. Thus, this teaching aid effectively increases students' motivation to learn and understand concepts (Aminulloh & Widodo, 2018). According to (Jannah et al., 2023), teaching aids developed in learning must follow sophisticated technological developments to look attractive and efficient, seeing current technological advances that have increased.

The quality of learning and student understanding of learning material will be more optimal if the learning process is accompanied by practicum. However, from the needs analysis results on 65 12th-grade science students at one of the Public High School in Bengkulu City, teachers still teach the Doppler effect material using the lecture method. Moreover, from the needs analysis, students agree that Doppler effect props are made and developed. In the needs analysis, students are very enthusiastic about the learning process of the Doppler effect by using teaching aids at school, and students agree that practicum is very well done in learning at school. However, students feel that infrastructure such as Doppler effect material props at school are still minimal, so students need props for the Doppler effect practicum.

Physics practicums in schools generally use simple equipment that cannot concretely show sound gliding events and the Doppler effect, where teachers usually only take qualitative data with a resonance tube sound box tool (Arifin et al., 2019). In previous research by Jannah et al. (2023), Arduino Uno-based Doppler effect props were obtained to detect sound. However, in this study, practicum props could only show Doppler effect events when observers and sources moved relative to limited trials. Based on this research, Doppler effect props were developed with different components, namely by using FC-04 sensors, HCSR-04 sensors, tracker sensors, motor drivers, DC motors, and buzzers.

The trainers developed to act as practicum props that can show the phenomenon of the Doppler effect in depth. Furthermore, the practicum props developed will be validated by experts to find out whether the practicum props developed are suitable for testing with students. After that, the practicum teaching aids will be tested on 12th grade Science students at one of the Senior High sSchools in Bengkulu City. So, the feasibility of developing Doppler effect props based on Arduino Uno with FC-04 sensors and HCSR-04 sensors can be known.

This research focuses on developing Arduino Uno-based Doppler effect props using the main components of an FC-04 sensor and HCSR-04 sensor.

RESEARCH METHODOLOGY

Research Methods

The research method used in this study is the research and development method or research and development (R&D). Research and development is a systematic study process that develops and validates products used in education (Andi et al., 2018). The development model used is ADDIE: Analysis, Design, Development, Implementation, and Evaluation (Ashari et al., 2023; Cahyadi, 2019).

Research Participants

The research subjects in this study consisted of two Physics education lecturers as media expert validators, one teacher at one of the Bengkulu City High Schools as material expert validators, and 65 12th-grade science students at one of the Bengkulu City High Schools.

Research Instruments

The research instruments used were a needs analysis sheet, material expert and media expert validation sheets, and student response sheets. The results of the analysis of the distribution of the needs questionnaire to 65 12th-grade science students at one of the high schools in Bengkulu City are the analysis stage of this research and development. The needs questionnaire aims to identify problems in the school.

The stages of designing Doppler effect props carried out in this study include five stages, namely the analysis stage, which analyzes the need for teaching aids, and the design stage, which designs the teaching aids in the form of both software and hardware. The Development stage at this stage is the development of teaching aids made from previous research. In the Implementation stage, the teaching aids that have been developed are implemented in one of the high schools in the city of Bengkulu; the Evaluation stage at this stage is the evaluation stage to assess the shortcomings and advantages of the teaching aids that have been developed.

Data Collections

Data collection was carried out through questionnaires. The questionnaire in question consists of a needs analysis questionnaire, a validation sheet given to material and media experts, and a response questionnaire given to students.

Data Analysis

The data obtained from data collection is divided into two types of data, namely quantitative data and qualitative data. Quantitative descriptive analysis techniques are used to describe product development results in the form of Doppler effect props that are tested for validation and feasibility. Data obtained through validators and students as respondents in the form of quantitative values will be converted into qualitative values. The data analysis used is as follows:

1. Media Expert and Material Expert Validation Sheet

Media expert validation sheets are used to obtain data information about the validity of Doppler effect props. Validity data was obtained from two media expert lecturers as validators. The step developed in analyzing data from Doppler props media expert validation sheets is to convert qualitative data into quantitative data using the Likert scale. Next, calculating the percentage of each statement is done using the equation:

$$\%X_{in} = \frac{\sum S}{Smaks} \times 100\%$$

Where $\%X_{in}$ is the percentage of the score obtained, $\sum S$ is the sum of all scores, and S_{maks} is the maximum score (Erlina et al., 2022). The criteria for the props media expert validation sheet can be seen in Table 1.

Table 1. Likert scale criteria due diligence of media and teaching aids materials

Interval (%)	Criterion
76%-100%	Very Worth It
51%-75%	Proper
26%-50%	Not Worth It
0%-25%	Very Unworthy

The development of Arduino uno-based Doppler effect props with FC-04 sensors and HCSR-04 sensors is said to be feasible or very feasible if it obtains a percentage scale ≥ 51.

2. Student Response Sheet

Student response sheets are used to obtain data on student responses to Doppler effect props. Then, the response result of each statement will be calculated using equation (1) above. The criteria for student response sheets to teaching aids can be seen in Table 2.

Table 2. likert scale criteria student response to props

Interval (%)	Criterion
76%-100%	Excellent
51%-75%	Good
26%-50%	Bad
0%-25%	Very Unking

RESULTS AND DISCUSSION

Results

The results of the development of Arduino U-based Doppler effect props with FC-04 sensors and HCSR-04 sensors were carried out using the stages of development research described by five stages of the ADDIE development model Analysis, Design, Development, Implementation, Implementation, and Evaluation. The stages of research on the development of Doppler effect props are as follows.

1. Analysis

Preliminary research, for instance, an analysis, aims to collect information and assess the problems and needs of students in the school environment using student needs analysis sheets. At the analysis stage, students provide data that will later become the basis for developing teaching aids. The results obtained from this stage are a needs analysis of 65 12th-grade science students at one of the Senior Public High Schools in Bengkulu City. These results showed that 76.79% of students strongly agreed that Doppler effect props must be made and developed. So, based on the initial needs analysis of this study, students need props to understand the Doppler effect material.

2. Design

The design stage is carried out by making a design. The first step in this stage is to know the tools and materials used to make Doppler effect props, considering the cost and time of working on the props. The results obtained from the design stage are in the form of developing the initial design of Doppler effect props in software and hardware design. In this study, two kit cars were needed for hardware; each kit car has a different function: one kit car functions as a sound source while two kit cars function as an observer. In addition, the Arduino IDE functions as software. The program code is created using Arduino IDE, which can be used to compile the program code, which will later be entered into Arduino Uno.

In this study, two program codes with different functions were used: a sound source and an observer. The data generated by the Arduino software will be displayed on the LCD screen. The flowchart of Doppler effect props can be seen in Figure 1.

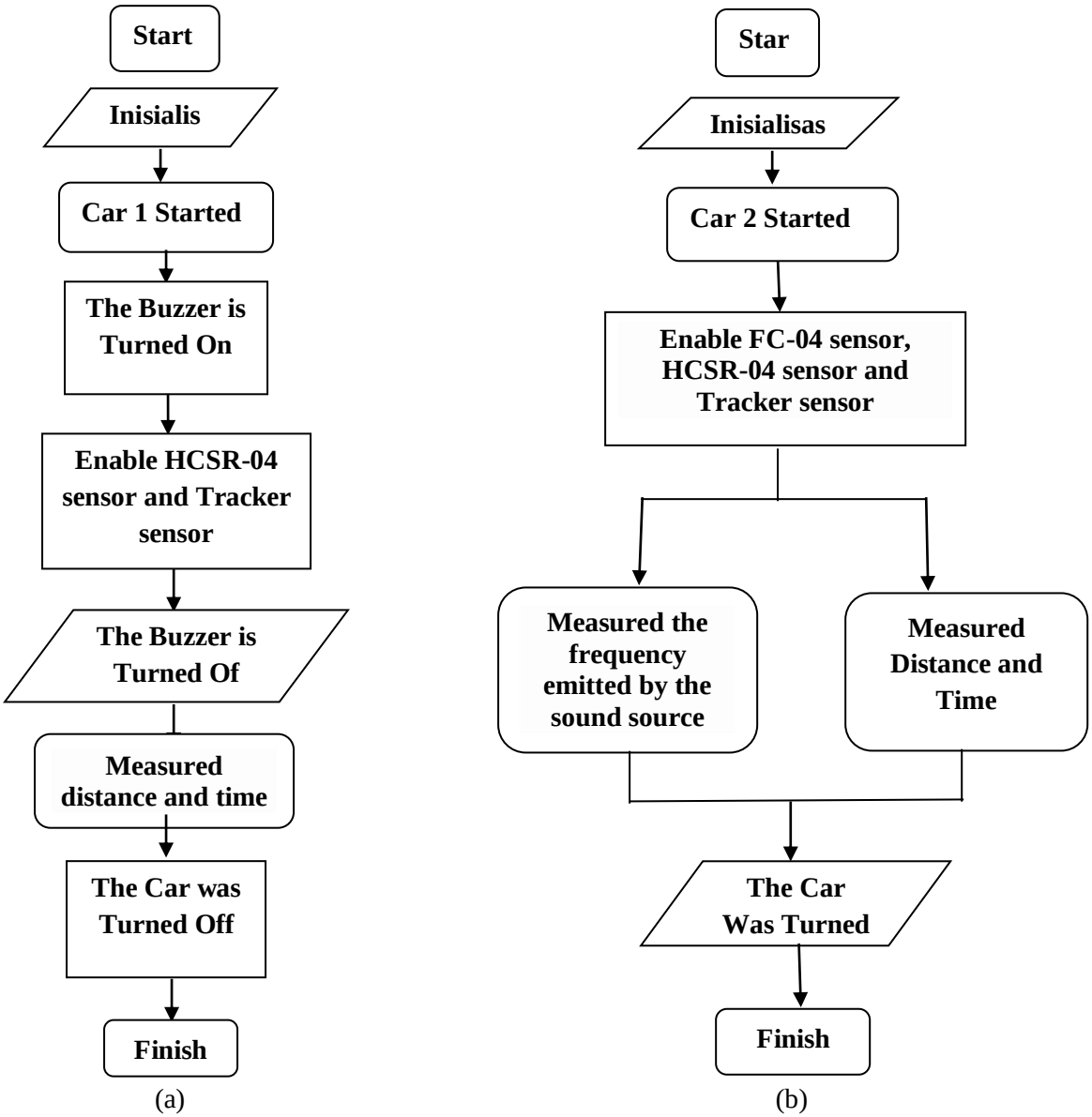
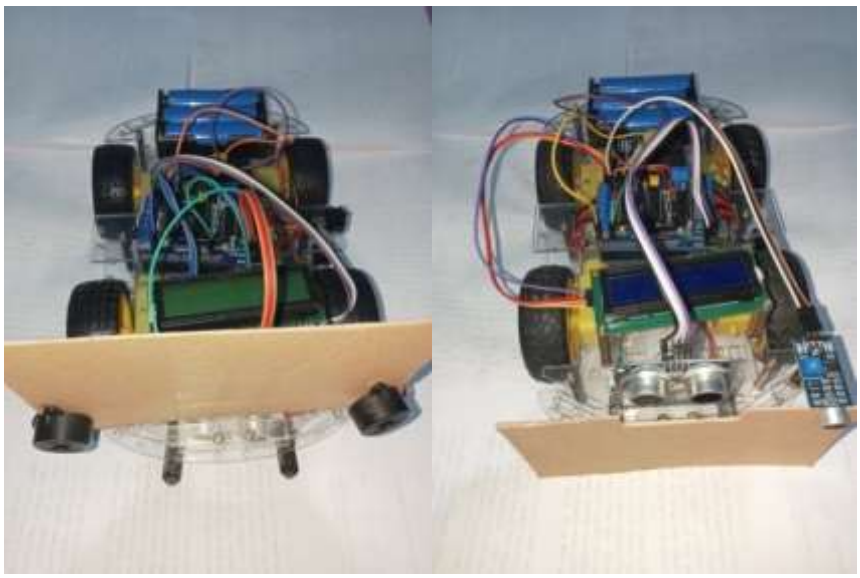


Figure 1. Flowchart Kit Car 1(a) Sound Source and Kit Car 2(b) Observer

3. Development

At the development stage, development is carried out based on the design that has been designed at the design stage. At this stage of development, product design realization activities in the form of Doppler effect props were carried out. The developed props can be seen in Figure 3.



(a) (b)

Figure 3. Arduino uno-based Doppler effects props with FC-04 sensor and HCSR-04 sensor (a) sound source and (b) observer

Measurement trials are carried out on the tool after it is generated to collect data that can be used as a source of information during learning. The test was conducted in a closed room with no additional sound sources. The data taken includes the correlation between Doppler effect measurement information and Doppler effect calculation data. The calculation formula for the Doppler effect is as follows:

$$f_p = \frac{v \pm vp}{(v \pm vs)} \mathrm{f_s}$$

Vs is positive when the sound source moves away from the source, Vs. is negative when the sound source approaches the observer, and Vp is positive when the observer approaches the sound source. Vp is negative when the observer moves away from the sound source (Habibi & Sucahyo, 2015; Haisy et al., 2015). With the frequency of the sound source made fixed, the speed varied, resulting in the lowest error and highest error; the error calculation formula is:

$$\text{Error} = \frac{[\text{Frequency of measurement results(Hz)} - \text{Frequency of calculation results(Hz)}]}{\text{Frequency of calculation results (Hz)}} x100\%$$

The following are the Doppler effect props trial results in each condition with a source frequency of 82.26 Hz. The test results of Doppler effect props on sound sources moving closer and stationary observers can be seen in Table 3; the results of testing Doppler effect props on sound sources moving away and stationary observers can be seen in Table 4. The results of the Doppler effect props test on the stationary sound source and the observer moving closer can be seen in Table 5, and the results of the Doppler effect props trial on the silent sound source and the observer moving away can be seen in Table 6. The results of the Doppler effect props trial on the source moving closer and the observer approaching can be seen in Table 7, and the results of the Doppler effect props trial on the source moving away and the observer away can be seen in Table 8.

Table 3. The Doppler effect on sound sources moving closer and the observer is still

No	Source Speed (m/s)	Observer Speed (m/s)	Frequency of measurement results (Hz)	Frequency of Calculation Results (Hz)	Error (%)
1	0,22	0	70,02	82,19	-0,14
2	0,24	0	75,01	82,20	-0,08
3	0,26	0	87,11	82,21	0,05
4	0,27	0	100,03	82,22	0,21
5	0,28	0	110,10	82,22	0,33

Table 4. The results of the Doppler effect test on the sound source move away and the observer is still

No	Source Speed (m/s)	Observer Speed (m/s)	Frequency of measurement results (Hz)	Frequency of Calculation Results (Hz)	Error (%)
1	0,20	0	110,02	82,11	0,33
2	0,23	0	98,03	82,10	0,19
3	0,34	0	85.12	82,07	0,03
4	0,39	0	70,14	82,06	-0,14
5	0,52	0	57,26	82,03	-0,30

Based on the results of measurements and calculations on the sound source moving closer, the observer can still be seen in Table 3. It was concluded that the Doppler effect data of measurements and calculations reached the lowest error of -0.08% and the highest error of 0.33%. The source moves away, and the observer is stationary, as seen in Table 4. It was concluded that the Doppler effect data of measurement and calculation reached the lowest error of -0.14% and the highest error of 0.33%.

Table 5. The results of trials of the Doppler effect on stationary sources and observers move closer

No	Source Speed (m/s)	Observer Speed (m/s)	Frequency of measurement results (Hz)	Frequency of Calculation Results (Hz)	Error (%)
1	0	0,22	72,12	82,21	-0,12
2	0	0,24	85,05	82,22	0,03
3	0	0,27	90.12	82,23	0,09
4	0	0,29	100,08	82,23	0,21
5	0	0,33	110,25	82,24	0,34

Table 6. Trial results of the Doppler effect on stationary sources and observers moving away

No	Source Speed (m/s)	Observer Speed (m/s)	Frequency of measurement results (Hz)	Frequency of Calculation Results (Hz)	Error (%)
1	0	0,21	110,15	82,10	0,34
2	0	0,22	100.02	82,09	0,21
3	0	0,33	80,11	82,08	-0,02
4	0	0,35	60,05	82,07	-0,26
5	0	0.45	45,12	82,05	-0,45

Based on the results of measurements and calculations on the sound source still and the observer moving closer, this can be seen in Table 5. It was concluded that the Doppler effect data of measurements and calculations reached the lowest error of -0.12% and the highest error of 0.34%. The source of the silent sound and the observer moving away can be seen in Table 6. It was concluded that the Doppler effect measurement and calculation data achieved the lowest error of -0.02% and the highest error of 0.34%.

Table 7. The results of the Doppler effect trial on the source move closer, and the observer approaches

No	Source Speed (m/s)	Observer Speed (m/s)	Frequency of measurement results (Hz)	Frequency of Calculation Results (Hz)	Error (%)
1	0,21	0,21	60,12	82,26	-0,26
2	0,24	0,23	72,15	82,27	-0,12
3	0,24	0,28	83,05	82,28	0,009
4	0,25	0,30	95,12	82,29	0,15
5	0,28	0,30	100,15	82,30	0,21

Table 8. The results of the Doppler effect trial on the source move away and the observer away

No	Source Speed (m/s)	Observer Speed (m/s)	Frequency of measurement results (Hz)	Frequency of Calculation Results (Hz)	Error (%)
1	0,19	0,22	110,15	82,06	0,34
2	0,22	0,23	80,02	82,05	-0,02
3	0,34	0,28	65,05	82,01	-0,20
4	0,37	0,34	45,12	81,98	-0,44
5	0,45	0,50	38,14	81,93	-0,53

Based on the results of measurements and calculations, the sound source moving closer and the observer moving closer can be seen in Table 7. It was concluded that the Doppler effect data of measurements and calculations reached the lowest error of -0.12% and the highest error of 0.21%. The sound source and observer moving away can be seen in Table 8. It was concluded that the Doppler effect measurement and calculation data achieved the lowest error of -0.02% and the highest error of 0.34%.

After conducting a trial calculation of props, expert validators carry out a feasibility analysis of teaching aids. The feasibility test of media on Doppler effect practicum props includes aspects of the relationship of tools with learning materials, containing educational value, tool durability, tool efficiency, safety for students, aesthetics, and technician components. The results of the due diligence by validators ahli media are shown in Graph 1.

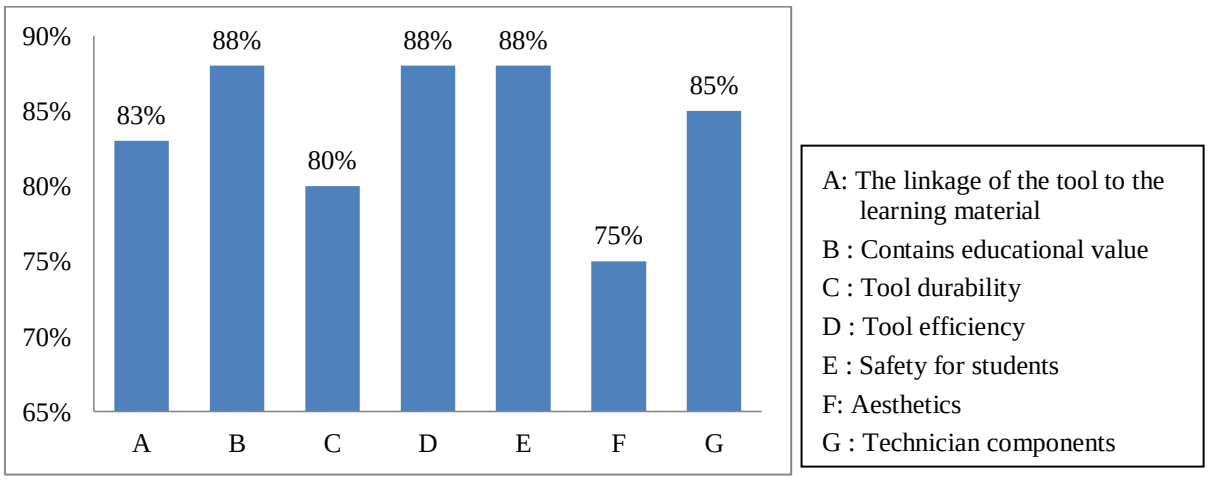


Figure 4. Doppler props media validation results

Material expert validators carry out material due diligence. Material feasibility tests include aspects of the relationship between teaching aids and learning materials and contain educational value. The results of due diligence by material expert validators are shown in Graph 2.

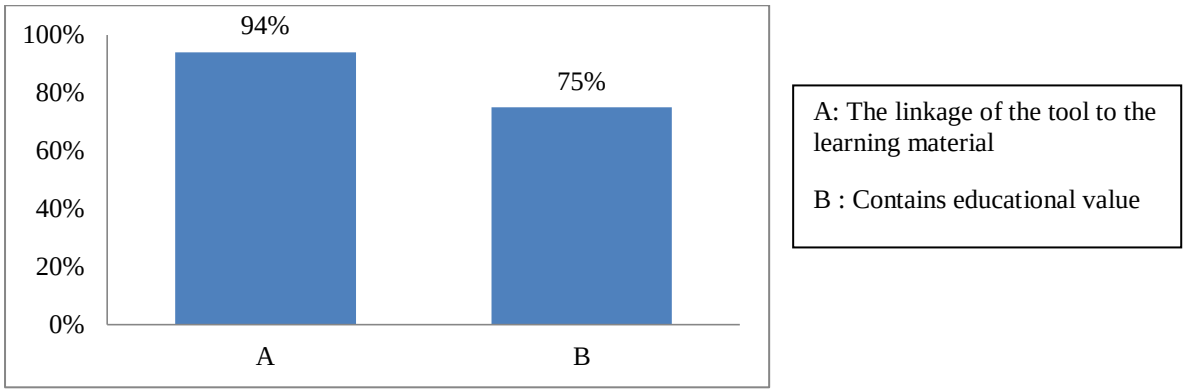


Figure 5. Doppler effect props material validation results

4. Implementation

After validating media experts and material experts on Doppler effect props that have been developed, then a trial was carried out at one of the high schools in Bengkulu City. The purpose of the trial is to determine the performance of teaching aids that have been developed, in addition to knowing the quality of teaching aids and the response of students with the Doppler effect props that have been developed. The process at this stage is carried out on class XII students at one of the Public High Schools in Bengkulu City. The results of the analysis of students' responses to Doppler effect props that have been developed can be seen in Graph 3.

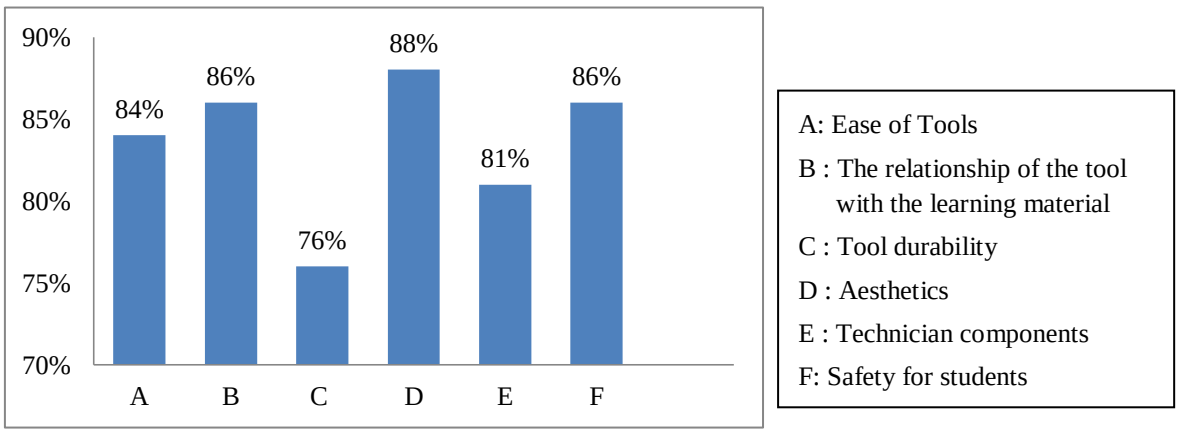


Figure 6. Results of student response analysis

An average percentage of 85% was obtained from analyzing student responses. Based on Table 2, the percentage criteria of student response can be categorized from various aspects. Arduino uno-based Doppler effect props with FC-04 sensor and HCSR-04 sensor are perfect.

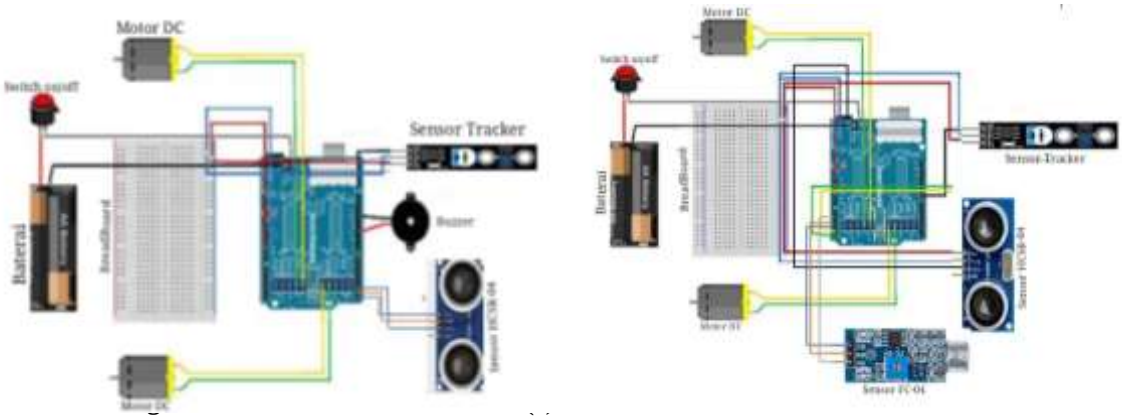
5. Evaluate

At this stage, Doppler effect props will be evaluated for advantages and disadvantages in context and construction. This stage is carried out to know the advantages and disadvantages of the developed Doppler effect props. Based on criticisms and suggestions, as well as improvements obtained from validation questionnaires and student responses to the teaching aids developed where the FC-04 sensor used in the circuit is too sensitive so that it is challenging to retrieve frequency data correctly where this teaching device requires a closed room that is soundproof so that the data obtained is precise enough. Then, the track used needs to be improved where the way used is only a straight line so that the props are constrained to be used in various conditions.

Discussion

In this study, two program codes with different functions were used: sound source and observer. Data generated by the Arduino software will be displayed on the LCD screen as shown in Figure 1. The tool components in car kit 1 consist of Arduino Uno, L293D driver motor, DC motor, 18650 battery, on/off switch, breadboard, LCD with I2C, HCSR-04 sensor, tracker sensor, jumper cable and buzzer. The tool components used in kit car 2 consist of Arduino Uno, L293D motor driver, LCD with I2C, FC-04 sensor, HCSR-04 sensor, tracker sensor, DC motor, 18650 battery, on/off switch, breadboard and jumper cable. These components are assembled and arranged based on each kit car using acrylic. Furthermore, each kit car is installed with an L293D motor driver connected to the Arduino Uno so that the Arduino Uno can control the motor driver's program. A jumper cable connects The installed DC motor to the L293D driver. The DC motor on the left is connected to pins M1 and M2 on the driver motor, which functions to control the direction of rotation of the left motor. In contrast, the DC motor on the right is connected to pins M3 and M4 on the driver motor to control the motor's rotation in a suitable direction.

This trainer uses various components, including the Arduino Uno, which controls the program for all components involved. The L293D driver motor is used to control the DC motor movement on the kit car, while the 18650 battery serves as a power source, and the on/off switch functions to regulate the flow of electricity. The FC-04 sensor converts sound waves into electrical quantities and can detect sound intensity around it. Sensor characteristics work in a frequency range of 50-500 Hz (Aprilia et al., 2022; Rasyid et al., 2023). In this tool, the HCSR-04 sensor detects distance, while the Tracker sensor controls the trajectory of the kit car. The buzzer serves as a sound generator. A buzzer is an electronic that converts electrical vibrations into sound vibrations. Buzzers work almost the same as loudspeakers (Al Fani et al., 2020). The buzzer frequency on this tool is set to output by 1kHz, so the buzzer produces a frequency that is significant enough. The circuit design scheme for kits 1 and 2 can be seen in Figure 2.



Based on the props developed in Figure 3, the props' characteristics show the phenomenon of the Doppler effect through observations from the FC-04 sensor. During the development process, a series of trainers called kits were produced. The concept developed at this stage is integrating all components into one circuit to easily carry and maintain the props. The components of the Doppler effect trainer, made using the FC-04 sensor and HCSR-04 sensor, consist of two car kits. Each kit car has a specific role, one as a sound source and the other as an observer.

The kit car that acts as an observer has FC-04 sensor components and HCSR-04 sensors. At the same time, the kit car that acts as a sound source has a buzzer component and an HCSR-04 sensor, where the buzzer functions as a sound producer. The frame used in this series is made of acrylic to make it safe. To secure the installation of the tool, nuts, and bolts are used as a connecting support between the support and the frame. When the sound source approaches or moves away, the sensor will begin to detect the frequency of the sound produced, and the results will be displayed on the LCD screen. This tool is powered by an 18650 battery with a capacity of 3500 mAH, selected according to power requirements.

Based on the average results of validation tests by experts, 85% of media experts are in the very decent category, and 85% of material experts are in the very decent category. Refer to the interpretation of the Likert scale in Table 1. So, the final assessment of each validator is that Arduino uno-based Doppler effect props with FC-04 sensors and HCSR-04 sensors that have been developed are worthy of trial. The results of this research are in line with research conducted by Jannah et al. (2023), which found that the Doppler effect practical teaching aid using the FC-04 sensor and Arduino Uno is good to use.

CONCLUSION

Based on the research results, a product was obtained in the form of Doppler effect props with FC-04 sensors and HCSR-04 sensors. We also got the results of an average percentage of validation by 85% of media experts, who are in the very decent category, and 85% of material experts, who are in the very proper category. After that, the Doppler effect props were demonstrated, so the percentage of student response was 85%, which is an outstanding category from the results of the class student response test at one of the Bengkulu City High Schools. As for this study, the Doppler effect props developed have sensors with high enough sensitivity so that they experience difficulties retrieving data. The data collection process must be carried out in a closed room that is soundproof and the track used must be a straight line track. In future studies, sensor sensitivity needs to be considered to facilitate data collection in any condition, and the trajectory used should be varied so that the course is not just a straight line.

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REFERENCES

Al Fani, H., Sumarno, S., Jalaluddin, J., Hartama, D., & Gunawan, I. (2020). Perancangan Alat Monitoring Pendeteksi Suara di Ruangan Bayi RS Vita Insani Berbasis Arduino Menggunakan Buzzer. *Jurnal Media Informatika Budidarma*, *4*(1), 144-149. https://doi.org/10.30865/mib.v4i1.1750

Aminulloh, A. M., & Widodo, W. (2018). The effectiveness of sound props to increase students' learning motivation and understanding of concepts.*e-jounal pensa*, *06*(02).134-140.

Andi, I., Asru, A.H., & Madi. (2018). *Research Methodology.* Makassar: Gunadarma Science.

Aprilia, R. D., Harijanto, A., & Subiki. (2022). Rancang bangun alat peraga fisik Efek Doppler menggunakan modul sensor suara dan arduino. *Jurnal Fisika Unand (JFU)*, *11*(2), 139–145.

Arifin, F., Indrasari, W., & Rustana, C. E. (2019). Development of sound service practicum tools and Doppler effects based on condenser microphone and microcontroller modules. *Proceedings of the National Seminar on Physics (E-Journal).VIII*,445–450.

Ashari, A., Anzani, P.W., Pratiwi, U., & Sriyono, S. (2023). Design of Physics Toys-Based Props on Doppler Effect Material Using RTC and Arduino.*Journal of Science Education Innovation (JIPS).4(1)*, 46–53.

Cahyadi, R. A. H. (2019). Development of Addie Model-Based Teaching Materials. *Halaqa: Islamic Education Journal*, *3*(1), 35–42. https://doi.org/10.21070/halaqa.v3i1.2124

Cahyo, V., Saputro, E., Admoko, S., &; Surabaya, U. N. (2019). Development of Carnot machine trainers as a learning medium with a guided inquiry learning model. *Journal of Physics Education Innovation*, *08*(02), 716–721.

Charli, L., Ariani, T., &; Asmara, L. (2019). The Relationship of Learning Interest to Physics Learning Achievement. *Science and Physics Education Journal (SPEJ)*, *2*(2), 52–60. https://doi.org/10.31539/spej.v2i2.727

Erlina, R., Risdianto, E., Hamdani, D., Fathurrochman, I., Efendi, R., & Prananosa, A. G. (2022). An Analysis of Needs Response to the Development of E-Module Material Elasticity and Hooke Law at Lebong Regency High School. *JMKSP (Jurnal Manajemen, Kepemimpinan, dan Supervisi Pendidikan)*, *7*(1), 163-187.

Haisy, M. C., Astra, I. M., & Handoko, E. Pengembangan alat peraga resonansi dan efek doppler berbasis soundcard pc/laptop untuk meningkatkan motivasi belajar fisika siswa SMA. P*rosiding Seminar Nasional Fisika (E-Journal)*, 4, 87-92.

Habibi, N., & Sucahyo, I. (2015). Perancangan alat ukur kecepatan menggunakan sensor ultrasonik dan prinsip efek doppler. *Jurnal Inovasi Fisika Indonesia*, *4*(3), 48–54.

Jannah, A. R., Hamdani, D., & Medriati, R. (2023). Pengembangan Alat Peraga Praktikum Efek Doppler Menggunakan Sensor FC-04 Dan Arduino Uno Di SMA. *Jurnal Penelitian Pembelajaran Fisika*, *14*(1), 75-85. https://doi.org/10.26877/jp2f.v14i1.13984

Kause, M. C. (2019). Design Arduino-Based Physics Props (Case Study of Free Fall Motion). *Cyclotron*, *2*(1),13-19. https://doi.org/10.30651/cl.v2i1.2511

Maryam, E., & Fahrudin, A. (2020). Development of Laptop Sound Card as a Physics Practicum Tool for Determining the Acceleration of Earth Gravity. *Silampari Journal of Physical Science Education*, *2*(1), 29–40. https://doi.org/10.31540/sjpif.v2i1.926

Melawati, O., Ngadimin, N., & Soewarno, S. (2019). The Development of Physics Student Skills Test Using Basic Physics Measuring Instruments. *Asian Journal of Science Education, 1*(1), 45-52.

Octaviani, L. A., Prastowo, S. H. B., & Anggraeni, F. K. A. (2021). Design Trainer Kit Design to Determine the Effect of Rope Material Type on Wave Propagation Speed. *JIPFRI (Journal of Innovation in Physics Education and Scientific Research*), *5*(1), 33–42. https://doi.org/10.30599/jipfri.v5i1.838

Rahmani, Y., Hamdani, D., & Risdianto, E. (2022). Development of basic physics experiment props 1 on fluid viscosity materials. *Amplitude: Journal of Physical Learning Sciences*, *1*(2), 128–137.

Rasyid, A. N., Hamdani, D., & Setiawan, I. (2023). Rancang Bangun Smart Greenhouse Berbasis Arduino Uno. *Jurnal Ilmu Pembelajaran Fisika*, *2*(2), 125–132.

Rizaldi, D. R., Jufri, A. W., & Jamaluddin, J. (2020). PhET: Simulasi interaktif dalam proses pembelajaran fisika. *Jurnal Ilmiah Profesi Pendidikan*, *5*(1), 10-14.. https://doi.org/10.29303/jipp.v5i1.103

Wahyuningsih, F. T., Hakim, Y. Al, &; Ashari, A. (2019). Development of water discharge measuring props using Arduino-based flow sensors as a fluid learning medium. *Radiation : Periodical Journal of Physics Education*, *12*(1), 38–45. https://doi.org/10.37729/radiasi.v12i1.31

Widaningrum, D. (2021). Design of Learning Media for Audacity-Assisted Doppler Effect Practicum Tools. *Journal of Physical Science and Innovation*, *5*(1), 13–18. https://doi.org/10.24198/jiif.v5i1.32035