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Development of Digital Heat Expansion Learning Media Based on Arduino Uno to Improve Students' Generic Science Abilities

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Abstract: Students are less able to develop their generic science skills, such as understanding symbols in science lessons, and many of them cannot even use measuring instruments. One way to improve this ability is to develop learning media. This research aims to develop learning media in the form of digital heat expansion based on Arduino Uno that is valid, practical and effective to improve students' generic science abilities. This research includes research and development by adopting the ADDIE development model. The product was tested at one of the state schools in West Lombok class VII. The research results show that the device validation is in the valid and reliable category. The results of observations of learning implementation with an average score of 93.46%, teacher response 98.28%, and student response 89.66% in the very practical category. N-gain is used to see the effectiveness of the product being developed and an indicator of awareness of scale in the generic ability of science is obtained which has the highest N-gain of 94%. The paired t test was used to see the difference between the pre-test and post-test in the trial class, it was found to be significant at 0.00 and it was concluded that there was an increase in generic science abilities. The conclusion obtained is that the development of digital heat expansion learning media based on Arduino Uno is feasible, very practical and effective for improving students' generic science abilities.

Keywords: Arduino Uno; Digital Heat Expansion; Generic Science; Learning Media.

Introduction

Drylands agroecosystems are closely related to Science is a knowledge that studies natural phenomena and analyzes them scientifically. Students will have a good understanding of science if they have generic science abilities. Generic scientific abilities are intellectual abilities resulting from a combination or complex interaction between scientific knowledge and scientific process abilities (Sandy, 2019). The quality of generic science abilities includes higher-order thinking abilities, communication abilities, reasoning abilities, and lifelong learning (Sanjaya et al., 2019). This ability is very important to increase students' understanding of science concepts. Generic scientific abilities guide students to think and act in accordance with their scientific knowledge (Syugiyanto, 2021) and basic thinking skills needed in science learning. This ability must be mastered by students to be able to think analytically and think at a higher level (Izetbigovic et al., 2019).

In reality, students are less able to develop their generic science abilities. This can be seen from the lack of ability of students to understand the symbols in science lessons, and many of them cannot even use measuring instruments. Learning at one of the schools in West Lombok uses direct learning and utilizes the environment. Some materials in science learning have often been carried out in practicums. However, some materials such as temperature and heat only use the environment such as ice and water due to inadequate experimental equipment.

One way to improve generic science abilities is to use media to support learning. Learning media is a tool used to make it easier for students to learn. According to Syariffudin et al. (2022), media refers to the tools and materials used in learning activities. The use of interesting media in learning will help increase the effectiveness of the process of conveying messages to

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students (Wahyuni et al., 2022). Choosing the right learning media can support the achievement of competencies or learning objectives during the teaching and learning process (Hasian et al., 2020).

The importance of using media in learning will support many aspects of students to maximize the learning process (Hasian et al., 2020). Innovative learning media that matches the description of the material so that it can visualize the concepts of the material to make it more concrete and easy to understand is really needed by students.

One of the science materials that requires media for learning is temperature and heat. Temperature and heat are concepts that are considered abstract because they cannot be observed directly and are difficult to observe (Azizah et al., 2020). Learning that directly involves students can reduce the possibility of students' misconceptions (Jhoni et al., 2022). Expansion is one of the sub-chapters discussed in temperature and heat.

Generally, objects will expand when heated, such as metal (Isnawati et al., 2020). The expansion coefficient determines how the size of an object increases with changes in temperature. The higher the coefficient of linear expansion of a metal, the higher the increase in length. A tool that can be used to investigate expansion is thermal expansion. Most of the tools currently available are still conventional and have not kept up with the demands of the current digital era. Therefore, it is necessary to design digital-based teaching aids (Syariffudin et al., 2022).

Learning media in the form of teaching aids that can be used for temperature and heat material, especially expansion, is digital heat expansion based on Arduino Uno. Arduino boards are microprocessors and are preferred in physics experiments because they are flexible and have the advantage of fast data collection (Sari & Kirindi, 2019). The use of Arduino Uno-based learning media can help in taking measurements because it is done automatically and the resulting data is more accurate (Jhoni et al., 2022). Arduino is able to support microcontrollers; can be connected to a computer using a USB cable. Arduino Uno is a microcontroller board that has 14 digital input/output pins (6 pins can be used for PWM output), 6 analog inputs and several other devices (Amarudin et al., 2020). Based on the description above, research needs to be carried out to develop digital heat play learning media based on Arduino Uno to improve students' generic science abilities.

Method

The type of research used in this research is Research and Development (R & D). The R&D method is a method used to produce certain products and then test the effectiveness of the products developed (Sugiyono, 2017). The development procedure used is the ADDIE Branch & Kopcha model. The ADDIE model is used because this model is appropriate for developing learning media, is developed systematically, and is easy to understand at each stage (Rustandi, 2021; Ashari et al, 2022). The ADDIE model consists of 5 stages, namely Analyze, Design, Development, Implementation, and Evaluation. The trial design used in this research is a qualitative and quantitative design. Qualitative design is used to see the feasibility and practicality of the product. Meanwhile, quantitative design is used for pre-test and post-test to obtain the effectiveness of the product being developed. Limited scale trials only use one experimental class with a one group pre-test-posttest research design.

The test subjects in this research were class VII students at a school in West Lombok. Data analysis in this development research includes data on feasibility, practicality and effectiveness. Validation is carried out by expert lecturers to test the suitability of the products, learning tools and instruments to be developed. The formula used is Aiken's formula (Formula 1).

$$V = \sum s/[n(c-1)] \quad (1)$$

Table 1. Criteria for Validation Evaluation Results

Scoring Results	Level of Validity
0.00 – 0.20	Very invalid
0.21 – 0.40	Invalid
0.41 – 0.60	Valid enough
0.61 – 0.80	Valid
0.81 – 1.00	Very valid

Reliability of learning devices uses the Formula 2.

$$PA = \left(1 - \frac{A-B}{A+B}\right) \text{x } 100\% \quad (2)$$

Table 2. Reliability Criteria

Value	Level of Reliability
0.00 – 0.20	Very unreliable
0.21 – 0.40	Less reliable
0.41 – 0.60	Reliable enough
0.61 – 0.80	Reliable
0.81 – 1.00	Very reliable

The formula used to calculate the practicality of the product being developed is the Aiken's formula (Formula 3).

$$\%\text{Response} = \frac{\text{obtained score}}{\text{maximum score}} \text{x} 100\% \quad (3)$$

Table 3. Practicality Evaluation Results Criteria

Score Results	Level of Practicality
0 – 20	Impractical
21 – 40	Less practical
41 – 60	Practical enough
61 – 80	Practical
81 – 00	Very practical

Next, an N-gain test will be carried out to measure the difference between the post-test and pre-test (Formula 4).

$$g = \frac{S_{post} - S_{pre}}{S_{max} - S_{pre}} \quad (4)$$

Table 4. N-gain Assessment Criteria

Value	Criteria
g ≥ 70%	High
30% ≤ g <70%	Medium
g < 30%	Low

The paired t test was carried out to test differences in the pre-test and post-test of students' generic science abilities. The paired t test was carried out using SPSS 16 with the following conditions:

1. If sig. > 0,05 then H_0 is accepted and H_a is rejected
2. If sig. ≤ 0,05 then H_0 is rejected and H_a is accepted

The hypothesis for the t test is as follows:

H_0 : There was no difference in the pre-test and post-test of students' generic science abilities

H_a : There are differences in the pre-test and post-test of students' generic science abilities

Result and Discussion

Analyze Phase

Activities carried out at the analysis stage are initial observations to obtain information related to field conditions which are used as a basis for developing research products. The analysis stage was carried out by applying a qualitative descriptive approach. The analysis stage includes initial analysis, student needs, media and materials. Initial analysis was carried out to examine the processes and problems in science learning at school. This analysis was carried out by conducting interviews with science teachers at one of the schools in West Lombok regarding science learning. The results of the interview obtained were that learning at the school uses an independent curriculum by implementing various learning models including direct learning, discovery learning, and problem based learning. Science learning is sometimes carried out in the laboratory if the material being taught allows for practical work and the tools are available. However, there is some science material taught in class using the demonstration method. The learning resources used are textbooks that have been adapted to the independent curriculum.

Analysis of student needs is carried out by giving questionnaires to students related to learning media. Students are more interested in learning by being directly involved in learning. However, students have difficulty using measuring instruments and understanding science symbols. Students prefer to try rather than learn just by listening to learning material. Students' ability to use practical tools and how to read measurement results and understand symbols can be improved with this media.

Media analysis was carried out to determine media needs in science learning in the classroom. The learning media developed is digital heat expansion media based on Arduino Uno. The learning media for thermal expansion has been found in many schools but is still conventional, so researchers use an Arduino Uno with a distance sensor and a temperature sensor. The use of Arduino Uno makes it easier for students to make observations and the results are easier to read and more accurate.

Students are often given learning through experiments, but some material is only through textbooks because there are no experimental tools available that can be used. One of these materials is temperature and heat. Students are less interested in temperature and heat material because students prefer rote material rather than calculations.

Design Phase

The product design being developed is created at this stage. The product developed is designed using Arduino Uno. Arduino Uno is used to make digital-based measurements of temperature and length increase. The research product developed is a digital heat expansion learning media based on Arduino Uno to improve students' generic science abilities with supporting tools, namely Learning Objective Flow (ATP), teaching modules, LKPD, and test instruments prepared based on the independent curriculum. The temperature sensors used are the DS18B20 sensor and the VL53L0X distance sensor. The metal is heated using alcohol, then the temperature measurement results and length increase are read on the LCD. However, after several developments the spirit was replaced with a heater so that the metal was not heated with fire but with steam because the heat of the fire interfered with the proximity sensor during testing. The distance sensor has also been changed to use a digital caliper so that the increase in length can be read clearly.

Thermal expansion is used to investigate changes in the length of a metal due to changes in temperature. The

temperature and increase in metal length can be measured using a thermometer and meter. However, the media developed uses sensors to measure temperature and length increase so that measurements can be carried out easily and accurately (Hafidianto *et al*., 2020). The temperature sensor and distance sensor are connected to the Arduino Uno. The use of the Arduino Uno board is because it is easy to use and apply and data is read more quickly (Sari & Kirindi, 2019).

Development Phase

The development stage is the stage for producing the product being developed. The product developed is a digital heat expansion learning media based on Arduino Uno. The products developed were subjected to expert validation tests along with supporting tools, namely ATP, teaching modules, LKPD, and generic science ability test instruments.

Digital heat expansion learning media was developed based on the design that has been created. The metals used are iron and brass. The product developed uses 2 DS18B20 temperature sensors to measure the increase in temperature due to heat transfer and a digital caliper as a distance sensor to measure the increase in length experienced by metal. The temperature sensor works by conduction by being placed close to the heated metal, while the distance sensor works by radiation by placing it at a close distance to the metal. The distance sensor used is a digital caliper because the increase in length of heated metal is easier to measure using a digital caliper with an accuracy of 0.01 cm. Calibration is carried out first for the temperature and distance sensors before use. The measured temperature and length increase will be read on the LCD. The metal is heated using steam that flows from the heater to the metal tip via a hose.

Figure 1. Digital Heat Expansion Based on Arduino Uno

The steam that flows will cause the temperature of the metal to increase. The temperature increase in the metal will be read on the LCD by bringing the temperature sensor closer to the metal. Before use, the temperature sensor and distance sensor are calibrated first. Product feasibility is obtained from validity and reliability tests. Validation is carried out to test the correctness of the devices and products being developed. Validation of products and supporting devices is carried out by three expert validators. Validation results are presented in Table 5

Table 5. Validation Results Data

Learning Product and Devices	Validation Result	Criteria
Flow of learning objectives	0.78	Valid
Teaching Module	0.84	Very valid
Digital heat expansion learning media based on Arduino Uno	0.78	Valid
Student worksheets	0.78	Valid
Science generic ability test instrument	0.76	Valid

Table 5 shows the validation results of the Arduino Uno-based digital heat expansion learning media of 0.78 and is categorized as valid so it is suitable for use in learning. The reliability test is carried out after the validity test. The reliability results of the products and supporting devices that have been developed can be seen in Table 6

Table 6. Results of Reliability Analysis of Products and Supporting Devices

Learning Product and Devices	Result			Mean	Category
	$PA_{1,2}$	$PA_{2,3}$	$PA_{3,1}$		
Flow of learning objectives	93.68	94.21	92.10	93.33	Very reliable
Teaching Module	93.52	94.44	93.52	93.83	Very reliable
Digital heat expansion learning media based on Arduino Uno	96.69	94.44	91.20	94.11	Very reliable
Student worksheets	99.07	96.30	95.37	96.91	Very reliable
Science generic ability test instrument	98.15	100.00	98.15	98.77	Very reliable

Table 6 shows the products and supporting devices that have been developed in the very reliable category so they are suitable for use in learning. Improvements to products and supporting devices are carried out based on suggestions from validators. Through feasibility tests, media and supporting devices are given suggestions for improvements including the addition of images and instructions for using tools for learning

media so that they are easy for students and educators to use.

Implementation Phase

The implementation stage is carried out to find out whether the product being developed can improve students' generic science abilities. The data obtained is in the form of data on the practicality and effectiveness of the product being developed. The results of the practicality test were obtained through observing the implementation of learning, teacher responses, and student responses. Practicality results data were obtained from trials of the products being developed. The trial was carried out for three weeks with three meetings. Data on the results of learning implementation can be seen in Table 7.

Table 7. Data on the Results of Learning Implementation in Class

Rated Aspect	Value (%)			Mean
	P1	P2	P3	
Introduction	84.00	92.00	96.00	90.67
Core	87.27	89.09	92.73	89.70
Closing	100.00	100.00	100.00	100.00
Rata-rata (%)	90.42	93.69	96.24	93.46
Kategori				Very practical

Table 7 shows the learning process during three meetings using digital heat expansion learning media based on Arduino Uno. The average score obtained was 93.46 in the very practical category so it was concluded that the learning was carried out well. Teachers are given response questionnaires to assess the devices and products developed. The teachers who were given the questionnaire were teachers who taught science subjects in the classes that were used as research subjects.

Table 8. Data on Teacher Response Results

Learning Product and Devices	%response	Category
Flow of learning objectives	100	Very practical
Teaching Module	96	Very practical
Digital heat expansion learning media based on Arduino Uno	92	Very practical
Student worksheets	100	Very practical
Science generic ability test instrument	100	Very practical

Data on student responses to learning was obtained through student response questionnaires. The student response questionnaire contains responses to learning activities using digital heat expansion learning media based on Arduino Uno.

Table 9. Data on Student Response Results

Rated aspect	Mean (%)	Category
Implementation of learning	89.01	Very practical
Student worksheets	90.10	Very practical
Digital heat expansion learning media based on Arduino Uno	89.88	Very practical
Rata-rata (%)	89.66	Very practical

Table 9 shows the results of student responses in the very practical category with a percentage of 89.66%. This statement is in line with research conducted by Hamzah *et al*. (2021) with the results of a temperature measuring instrument using an Arduino Uno-based LM35 sensor as a very practical physics learning medium with a value range of 81% - 100%.

Product quality is measured by conducting effectiveness tests. The product developed is validated and implemented in learning. The implementation of this learning media was carried out with a limited scale test. Limited scale trials were carried out to see the effectiveness of the product on temperature and heat materials. The trial of the Arduino-based digital heat expansion learning media was carried out by looking at the students' generic science ability scores before and after being taught using this media.

Increasing students' generic science abilities through Arduino Uno-based digital heat expansion learning media can be measured using the N-gain test. The N-gain test shows that digital heat expansion learning media based on Arduino Uno can improve the generic science abilities of students in the medium category. The following is data on the N-gain value of students' generic science abilities.

Table 11. N-gain Value of Generic Science Ability

Indicator	N-gain (%)	Category
Direct observation	69	Medium
Indirect observation	69	Medium
Awareness of scale	94	High
Symbolic language	93	High
Logical inference	49	Medium
Logical framework	72	High
The law of cause and effect	36	Medium
Mathematical modeling	82	High
Building a new concept	40	Medium

Based on Table 11, it can be seen that generic science abilities are in the medium category for improvement. The results obtained are in line with research conducted by Yuliyanti et al. (2016) by using a virtual laboratory to improve generic science abilities so as to obtain an increase in abilities in the medium category. The legal cause and effect indicator has the lowest percentage of 40% and is categorized as experiencing a moderate

increase. This is because some students are still unable to provide an explanation of the causes of a phenomenon based on theory. The highest N-gain value was seen in the awareness indicator about the scale with a percentage of 94% and was categorized as experiencing a high increase. This can happen because during learning students begin to understand symbols and units through observing and investigating activities using digital heat expansion learning media based on Arduino Uno. The LCD screen displays symbols and units for temperature and length so that students start to get used to it as learning continues. The results of the N-gain of science generic ability for each indicator can be seen in Figure 2.

The difference in pre-test and post-test results in the trial class was seen using the t test. The t test used is the paired t test because the data tested are the results of the pre-test and post-test in the same class. This test is used to see the differences in abilities obtained by samples in the same class after and before being given treatment. Data processed using the t test must be normally distributed so a normality test is carried out first. The paired t test was carried out to see the differences in the pre-test and post-test of students' generic science abilities. The test results for generic science abilities are as follows (Table 12).

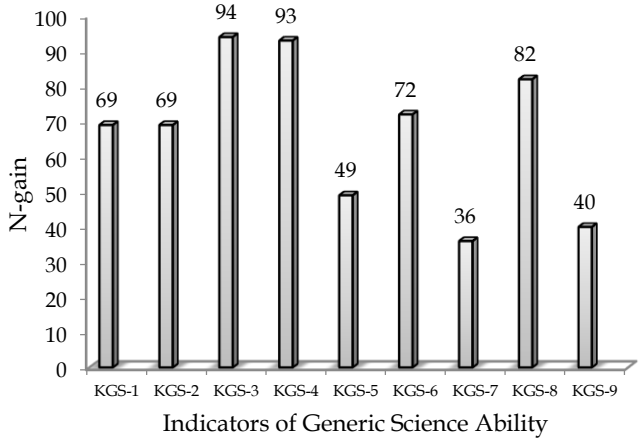

Figure 2 N-gain Generic Science Capability

Table 12. Results of the t Test for Generic Science Ability

Variable	Mean		Lowest value		Highest value		Sig.
	Pre	Post	Pre	Post	Pre	Post	
Generic science ability	19.59	69.16	13.46	50.00	25.00	93.27	0.00

Table 12 shows that there is a significant difference between the pre-test and post-test of generic science abilities. This can be seen from the significant value obtained after carrying out the t test, namely 0.00, less than 0.05, so it can be concluded that there is a difference between the pre-test and post-test of students' generic science abilities.

Differences in pre-test and post-test scores for generic science abilities were also seen using the paired t test. The paired t test was carried out using SPSS 16. This test was chosen because what was seen was the difference between the pre-test and post-test in the same class. The paired t test is used to see differences in the ability test results of students in the same class. Based on the tests that have been carried out, it was found that there was a difference between the pre-test and post-test of generic science abilities.

Each product developed has advantages and disadvantages. The advantages include being able to carry out measurements more precisely because the measurement results will appear directly on the LCD screen. This media also uses steam to distribute heat so it is safe for middle school children to use. Meanwhile, the weakness of the product being developed is that its quantity is limited so its use is uneven. This is due to limited costs and time. There is only one product being developed so it takes a long time for all students to try using it. This was circumvented by providing different representatives for each group at each meeting to use digital heat expansion media based on Arduino Uno.

Evaluation Phase

Evaluation is carried out at the end of each ADDIE stage. Evaluation is carried out by making improvements to the products developed based on the validation, practicality and effectiveness that have been carried out. At this stage, dissemination was also carried out by including articles published in accredited journals and distribution in one of the schools in Mataram. An obstacle encountered during research was a distance sensor error when developing digital heat expansion learning media based on Arduino Uno. The distance sensor could not be used because it was disturbed by the fire used to heat the metal so it was replaced with steam, the metal was replaced with a hollow rod, and the distance sensor was replaced with a digital caliper. Another obstacle found was when looking for a school where the distribution would take place. The distribution was close to the mid-semester exams so researchers had difficulty finding schools that still taught temperature and heat material.

Conclusion

Based on the objectives and results of observations, it can be concluded that the digital heat expansion

learning media based on Arduino Uno is feasible, very practical and effective for improving students' generic science abilities. The indicator of generic science ability that has the highest N-gain is awareness of scale at 94% and the lowest is the law of cause and effect at 36%. The difference between the pre-test and post-test was seen using the paired t test and obtained a significant value of 0.00, meaning that there was a difference in the students' generic science abilities before and after being given treatment using Arduino Uno-based digital heat expansion learning media in learning.

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