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# Enhancing 21st Century Skills for Prospective Physics Teachers through Arduino-Based Multiple Representations in Learning Heat and Temperature

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**Abstract:** There was a gap between traditional teaching and future demands and need a bridge by offering an innovative approach that allows prospective physics teachers to develop key abilities. The main purpose of this study was to improve prospective physics teacher' 21st century skills in heat and temperature by applying multiple representations learning using Arduino based experiment. The research method used is based on the development procedures of the ADDIE research and development model which includes the stages of analysis, design, development, implementation and evaluation. This study implemented design-based research with a one-group pre-post observation design. The research was conducted on 22 prospective physics teacher students. The teaching materials that have been developed passed the first stage test with a Very Good result. The validity test is assessed by expert validators. The response of students using the teaching materials is Good. In terms of effectiveness, the learning with Arduino based multi representations is able to improve the 21 st -Century Skills with an average N-Gain score of 0.35. Therefore, it can be used by lecture and those in other science fields to improve the quality of learning and developing prospective physics teachers' 21st Century Skills.

**Keywords:** Arduino; Multiple representation; Prospective physics teachers

## Introduction

In the last few decades, education has undergone changes that have fundamentally changed the way of learning and teaching. The era of disruption, where technology, globalization, and social change are occurring, has created a learning environment that is very different from the past (Horn & Staker, 2017; Muralidharan et al., 2019). In today's learning, we are required to train "new" skills that are relevant to this change, namely 21st Century skills. These skills have become an important benchmark for students as preparation for pursuing a career and future life (Chu et al., 2021; Kivunja, 2014). For this reason, the educational environment must also be designed to provide experiences and opportunities for students to develop these skills (Ağaoğlu & Demir, 2020; Chalkiadaki, 2018; Kivunja, 2014). In essence, the subject of physics holds the responsibility of structuring educational experiences that enhance students' proficiency in 21st Century Skills.

Currently, the development of 21st century skills is increasingly emphasized in a modern and dynamic educational environment (Malik, 2018). So it is necessary to prepare future teachers who are ready for this change.

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The role of teachers has evolved as the world has become more connected and driven by technology (Kim et al., 2019; Kivunja, 2014). In the field of science education, such as physics, it is very important to equip prospective teachers with the modern pedagogical tools and skills necessary to manage a more modern and dynamic classroom. This investigation focuses on developing 21st century skills for prospective physics teachers, taking into account the changing demands of education in the digital era. Learning has evolved to include students' skills in critical thinking, communication, teamwork and creativity (Hadinugrahaningsih et al., 2017; Khoiri et al., 2021). This research aims to bridge the gap between traditional teaching and future demands by offering an innovative approach that allows prospective physics teachers to develop key abilities.

At this time, learning science using microcontrollers or Arduino has become an interesting theme. Arduino is a device that can be used to control components in a circuit so that they can be automatically connected or disconnected. Providing students with knowledge about Arduino and other open access learning resources can increase their knowledge and solve physics problems beyond textbooks and laboratory demonstrations (Vallejo et al., 2020; Yasin et al., 2018) . In other research on the "the color of light" project it was also found that Arduino was able to arouse students' curiosity and allow teachers to emphasize LED technology in everyday life (Huy et al., 2022).

The application of multiple representations in learning for prospective physics teachers is one way to develop 21st century skills (Fatmaryanti et al., 2018; Voogt et al., 2013). Apart from that, it also shows that there are innovative strategies in preparing educators to face changes in the educational environment. Several studies have shown that multiple representations can improve learning and understanding in physics (Fatmaryanti et al., 2019). Students can study abstract topics using visual representations, images, mathematics, and even experiences (Larkin, 2014). These different representations not only accommodate different learning styles, but also encourage a more comprehensive understanding of complex subjects. Multiple representations bridge the gap between actual experiences and abstract theories, ultimately leading to richer conceptual comprehension (Bengio et al., 2013). Multiple representations have a close relation with 21th century skills. For example the investigation about the junction of multiple representations and 21st century abilities in the context of science education (Chalkiadaki, 2018). Their findings imply that using a variety of representations not only improves information comprehension but also encourages critical thinking and problem-solving skills. Furthermore, including technology-driven tools, such as Arduino based experiments, provides prospective teachers with the opportunity to build technology integration and adaptability skills.

Physics lessons have topics that are very close to everyday life and technological developments. However, it is still found in several studies that students have difficulty learning physics (Suprapto et al., 2017; Vijaya et al., 2017). One physics topic that confuses students is heat and temperature. Complexities in understanding heat and temperature emerge across science curricula spanning elementary, secondary, and advanced education levels (Seah & Yore, 2017; Yeo et al., 2021; Yuliana et al., 2019). Students particularly struggle with grasping the notion of heat transfer through conduction, as well as distinguishing between metal and non-metal seat belt materials (Yuliana et al., 2019). Students' misunderstandings about heat and temperature were found regarding the relationship between the temperature of an object and its size (Ni'mah et al., 2019). Students often gain conceptual understanding based on interpretations formed through everyday experiences (Ni'mah et al., 2019; Wahidah S. et al., 2017). To better understand physics concepts and reduce wrong interpretations, students can express these concepts in various ways or forms (multiple representations). Multiple representations are representations of concepts in various ways such as verbal, graphic, diagrammatic, etc.

According to the background, this research aimed to improve prospective physics teacher' 21st century skills in heat and temperature by applying multiple representations Learning using Arduino Based Experiment. This prior research will be conducted by designing and analyzing the lesson plan, the worksheet, and the test instrument of 21st century skills on heat and temperature implemented to prospective physics teacher.

## Method

This research uses a research and development approach to produce certain products. The series of steps in the research follow the development procedures of the ADDIE research and development model which includes the stages of analysis, design, development, implementation and evaluation which can be seen in Figure 1. The use of the ADDIE Model design is based on the consideration that the basic steps in design are simple , practical, easy to understand, and easy to apply in designing learning media and devices. The following section outlines the stages of the research.

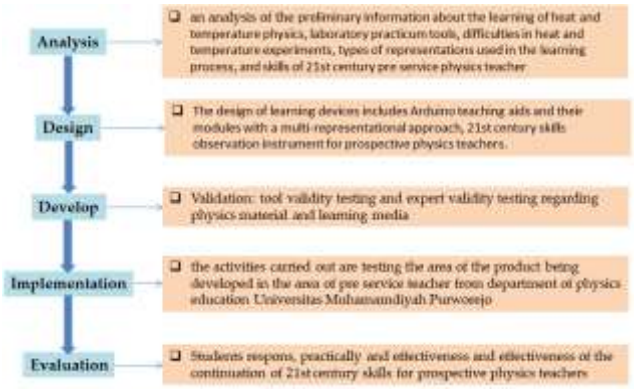


**Figure 1.** ADDIE Model Stage of Development

The analysis stage is carried out in several ways including field studies and literature studies. A needs analysis is performed at this stage to obtain detailed preliminary information about the learning of heat and temperature physics, laboratory practicum tools, difficulties in heat and temperature experiments, types of representations used in the learning process, and skills of 21st century prospective physics teacher. Observation is a data collection strategy. In addition, through literature research (article studies), a study of 21st century skills measurement instruments and multi-representation was carried out in experiments with Arduino.

At the design stage, tool design and guide design are carried out. Tool design includes 2 stages, namely hardware and software design. The design guide focuses more on the application of multiple representations in presenting experimental data. Meanwhile, in the development stage, tool validity testing and expert validity testing regarding physics material and learning media were carried out.

At the implementation stage experimental research was carried out with a quantitative design. Pre-experimental Design is chosen as one of the experimental research methods to discover a causal relationship only by involving one group of the subject. In other words, this method is used when there is no control group or extraneous factors which can influence internal validity (Fraenkel, Wallen & Hyun, 2011). To measure the improvement of students' 21 st -Century Skills, Gain analysis is used with Equation

$$\langle g \rangle = \frac{\langle S_{post} - S_{pre} \rangle}{100\% - \langle S_{pre} \rangle} \quad (1)$$

The improvement of students' 21 st -Century Skills is assessed based on three categories, namely low ($g<0.3$), moderate ($0.3<g<0.7$), and high ($g>0.7$).

At the evaluation stage, the researcher evaluated the teaching aids with Arduino based on multi-representation and the handbook that had been prepared to determine the practicality and effectiveness of the continuation of 21st century skills for prospective physics teachers.

## Result and Discussion

Research results on the development of this product is given by detail each stage as the follows.

*Analysis*

Based on field observations, there is no physics learning material using multi-representation-based physics teaching aids that integrate Arduino as an assistant. The learning tools produced are relatively new because they use technology-based media. The use of technology in learning has been proven to influence learning outcomes (Hunaidah et al., 2022). At this stage, an analysis of the learning material is carried out. The material used is temperature and heat with the topic of specific heat.

Apart from that, researchers also conducted a preliminary study regarding indicators of 21st century skills needed by prospective physics teachers. From several literatures, it was found that there are 4 aspects known as 4C, namely creativity, critical thinking, communication and collaboration (Kim et al., 2019; Kivunja, 2014; Novitra et al., 2021). Indicators for each aspect are as presented in table 1.

**Table 1.** 21st Century Skills for prospective physics teacher

| Aspect | Indicator |
|---|---|
| Creativity | Identify problems creatively |
| | Identify sources of information |
| | Generate and select ideas |
| | Presenting results |
| Critical thinking | Analyze leading questions |
| | Gather information |
| | Evaluate information |
| | Consider alternative answers to leading questions |
| Communication | Explain ideas and information |
| | Arrange presentation times |
| | Using presentation tools |
| | Respond to questions |
| Collaboration | Participate in groups |
| | Respect others |
| | Organizing tasks |
| | Work as a whole group |

*Design*

At the design stage, the design of temperature and temperature teaching aids with arduino based on multi-representation, manuals has been obtained use of tools, experimental guidebooks, and 21st century skills tests of

prospective physics teachers. To design this tool, several tools and materials are needed which are grouped into two parts, namely hardware and software. Arduino IDE software, Blynk and Fritzing. While hardware such as ESP8266, Load Cell Sensor, DS18B20 Sensor, HX711 Module, 16x2 LCD, I2C Module, 4.7k Resistor, Jumper Cable, Project Board, USB and Push Button as seen in figure 2.

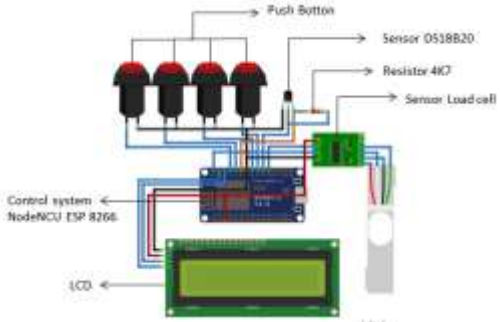


**Figure 2.** Hardware design

Arduino programming sketches was made using the Arduino Uno software series 1.8.5. Programming consists of 4 parts, namely define program, wifi program, and include program and main program. Define program, namely the program for defining the magnitude and sensor input pins, Wifi program, namely the connecting program between sketch and the Blynk application, the include program is a program that will tell the compiler that the program we are making will use the registered files and the main program is the main program that will be used to calculate the specific heating value of an object. A program project on the Blynk application will be connected directly via Android.

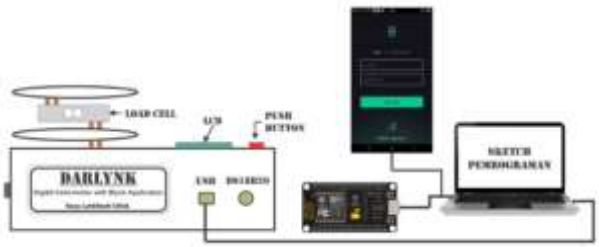


**Figure 3.** Software Design

After designing the tool, the researcher designed an experimental guidebook (Figure 4) which included a guide to using the tool, presenting experimental data with several representations, and a discussion guide.


**Figure 4.** Display of the experimental guidebook with data presentation using multiple representations

*Develop*

*Test the validity of experimental tools*

In this stage, the testing of the load cell sensor with a capacity of 5 kg was carried out to determine the accuracy of the sensor readings the weight of the object and the percentage of errors that occur on the scales. In the load cell sensor testing system is done by calibrating the results of sensor readings with digital weights which are commonly used as a reference in measuring the weight of objects at the Physics Education Laboratory, Muhammadiyah University, Purworejo. Of the 10 times the measurement results obtained an average error of 0.1%.

The next step is eccentricity testing to determine the performance of the scales in giving weighing results when the same load is placed in different positions. To see the position of laying the standard load (100 gram) and the eccentricity test table, the scales are presented in Figure 5 and Table 2.

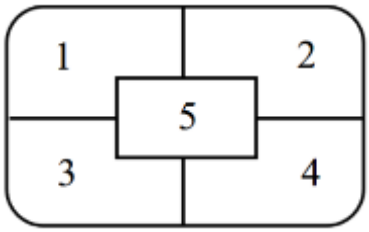


**Figure 5.** The laying position of the standard load

**Table 2.** The test results of the eccentricity of the scales

| Position | Rate load | Eccentricity |
|---|---|---|
| 1 | 99.72 | 0.28 |
| 2 | 99.82 | 0.12 |
| 3 | 99.72 | 0.28 |
| 4 | 99.98 | 0.02 |
| 5 | 99.88 | 0.12 |

*Test the validity of expertise*

The validity of the application was assessed by experts in physics materials and learning media. The results of testing the validity of expertise on multi-representation-based Arduino teaching aids and the guidebook can be seen in Table 3, 4 and 5. The validity

of the content eligibility, multi-representation, and language aspects were 86.00, 87.20, and 89.00, respectively. These aspects fall into the Very Good category. Furthermore, the average score obtained for the material validity test is 87.44 which is included in the Very Good category. The validation results from learning media experts are included in the good category with a mean of 82.73. The results of expert validation of the 21st century skills observation instrument are included in the good category with a mean of 85.42.

**Table 3.** Validity test results for physics material experts

| Aspect | Score | Category |
|---|---|---|
| Content eligibility | 86.00 | Very Good |
| Multi-representation | 87.20 | Very Good |
| language | 89.00 | Very Good |
| Average | 87.44 | Very Good |

**Table 4.** Validity test results for learning media experts

| Aspect | Score | Category |
|---|---|---|
| Presentation | 82.82 | Good |
| Physical appearance | 83.46 | Good |
| Quality of performance design | 84.42 | Good |
| Communicative | 79.27 | Good |
| Average | 82.73 | Good |

**Table 5.** Validity test results for instrument observation of 21st Century Skills prospective physics Teacher

| Aspect | Score | Category |
|---|---|---|
| Language | 84.51 | Good |
| Content | 86.32 | Very good |
| Average | 85.42 | Good |

*Implementation*

Regarding the implementation of learning, students obtain multiple representations of multiple conceptions during the learning process of the concept of heat and temperature. Conceptualization is implemented through displaying data generated from the Arduino props. Students are then directed to fill in questions related to the representation of heat and temperature through worksheets in the guidebook. At the conceptualization stage, students are asked to translate the emerging concept of heat and temperature into verbal representations, graphs, mathematical equations and energy bar diagrams. In practice, students are given the opportunity to use Arduino teaching aids in their respective groups. Directly students can see and understand the heat received and heat released from the black principle through the graph of heat with temperature. Students are also given concept reinforcement through mini quizzes that support students' deepening of the ability to represent each of their answers in various representations.

**Table 6**. Pre-Post Observation Data for 21st Century Skills

| Observed Aspect | Score Average | | Gain | Category |
|---|---|---|---|---|
| | Pretest | Post | | |
| Creativity | 55.22 | 74.00 | 0.46 | Moderate |
| Critical thinking | 47.38 | 65.41 | 0.34 | Moderate |
| Collaboration | 70.65 | 75.60 | 0.27 | Low |
| Communication | 60.54 | 77.27 | 0.42 | Moderate |
| Average | 57.70 | 73.07 | 0.35 | Moderate |

In the initial observation (pre-observation) it was found that creative and critical thinking skills were low. And in the end it can reach the moderate category at post-observation. This indicates that the problem the habit of students who only accept other people's opinions without any desire to discuss their opinions can be overcome. This proves that the use of teaching aids accompanied by initial discussion guides motivates students to prepare themselves before studying. From several studies it was found that the use of IT in learning provides intrinsic motivation so that students can learn actively and confidently (Kirkwood & Price, 2014; Lepper & Malone, 2021; Lin & Chen, 2017).

In the aspect of collaboration skills have not yet reached the high category, even though the pretest had the highest score. In the aspect of communication skills have moderate category. This is because in this learning student can explain their answer with different representation. In other research, it was stated that students who can represent problem solving in more than one representation (multiple representations) tend to have a higher understanding of concepts and are able to communicate better than students who only use one representation (Kusumawati et al., 2015).

*Evaluation*

Evaluation needs to be done to determine user response to the product made. The results obtained are in the form of student responses to aspects convenience, content, presentation and design, that is can be seen in Table 7.

**Table 7.** Students' responses to the product

| Aspect | Score | Category |
|---|---|---|
| Convenience | 82.44 | Good |
| Content | 87.20 | Very Good |
| Presentation | 86.46 | Very Good |
| Design | 84.85 | Very Good |
| Average | 85.23 | Good |

Based on the results in Table 7 then it can be observed that the app is in very good condition categories based on content, presentation, and design with a score of 87.20 respectively; 86.46; and 84.85. And the application is in the good category based on its

convenience aspect with a score of 82.44. These results explain that teaching aids with Arduino based on multi-representation have been designed to be suitable for students as learning materials.

## Conclusion

This study offers light on the transformative potential of integrating Arduino-based multiple representations into pre-service physics teachers' education, with a focus on improving their 21st century skills in the context of understanding heat and temperature concepts. The combination of modern pedagogical techniques, technological integration, and subject mastery provides a holistic approach that is in line with the changing demands of education in modern times. In terms of effectiveness, the learning with Arduino based multi representations is able to improve the 21 st -Century Skills of students with an average N-Gain score of 0.35. Therefore, it can be used by lecture and those in other science fields to improve the quality of learning and developing prospective physics teachers' 21st Century Skills. In brief, the integration of Arduino based multiple representations is a promising paradigm for improving prospective physics teacher preparation. The results of this research not only offers to the enhancing discussion on new teaching techniques, but it also expects a future in which educators are empowered to develop students who are not only knowledgeable, but also equipped with the abilities needed to succeed in the complexities of the twenty-first century.

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**Author Contributions**
Fatmaryanti: student analysis, concept analysis, writing the original draft; Kurniawan: conceptualization, validation and editing; Hakim: Software and data analysis; Ulfah: Software and data analysis; Sarwanto: writing and review.

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**Conflicts of Interest**
The authors declare no conflict of interest.

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