IMPLEMENTATION OF ARDUINO-ASSISTED 5E LEARNING MODEL IN PHYSICS ONLINE LEARNING

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ABSTRACT

As communication technology develops, online learning grows significantly. However, online physics learning still faces constraints related to incorporating laboratory work. This paper reports on the implementation of the Arduino-assisted 5E learning model in physics online learning. The learning phase consists of engagement, exploration, explanation, elaboration, and evaluation. The learning strategy includes Arduino-based hands-on physics experiments conducted by students at home. The learning model is implemented in a class consisting ten college students majoring in physics education. We also investigate the effect of the learning model on improving students' understanding of thermal physics. Our study shows that students' understanding of thermal physics improves moderately, with an average N-gain of 0.56.

***Keywords**: 5E learning model, Arduino, online learning, thermal physics, laboratory work*

INTRODUCTION

Distance learning has transformed significantly as digital technology developed tremendously. Accessibility to the internet and communication technologies can facilitate interaction among students and teachers during distance learning (Lenkaitis, 2020). The COVID-19 pandemic emerged in early 2020, forcing everyone to maintain social distance. It causes the education sector worldwide to shift face-to-face learning into distance learning using online sources. A sudden surge in online learning has been seen since the beginning of the COVID-19 pandemic (Dhawan, 2020).

The online platform has improved distance learning for a lot of subjects significantly. However, there is a big challenge for science subjects, including physics courses. Incorporating laboratory work in distance learning is still challenging. Laboratory work is an essential part of the learning process in physics courses. It stimulates students to practice inquiry, critical thinking, science process skills, and generating scientific information. Moreover, studies show that incorporating laboratory work in physics courses can improve students' attitudes toward science(Musasia et al., 2012).

To preserve laboratory work during distance learning, many colleges in Indonesia have used some alternatives, such as using experiment simulations, pre-recorded experiment demonstrations, live demonstrations,

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and video modeling tools (Aththibby et al., 2021; Pratidhina et al., 2020). Those alternatives are suitable for indirectly showing scientific phenomena to students. However, they cannot facilitate students to practice hands-on skills. Hence, some schools also proposed conducting scientific experiments at home (Pols, 2020). Resources to experiment at home are limited. Fortunately, a low-cost microcontroller board, called Arduino Uno, can be used to perform various physics experiments at home (Pratidhina et al., 2021).

Student-centered, active, and inquiry-based learning are well known as effective educational approaches for science subjects (Forrest et al., 2021). Those approaches have successfully improved student motivation, retention, and learning outcomes. 5E learning cycle, which consists of engagement, exploration, explanation, elaboration, and evaluation, is one of the inquiry-based learning cycles that has been widely implemented in science learning(Cigdemoglu, 2015; Şahin et al., 2017). However, the study on 5E learning cycle implementation in online learning is still limited.

In this paper, we explain the implementation of the 5E learning cycle in an online physics course, in which home experiment activity is incorporated. We delivered Arduino-Uno-based experimental kits to students to support the home experiment activity. Arduino UNO is an open-source microcontroller board that can be used for physics experiments. It can be connected to various sensors to measure physical quantities, such as temperature, pressure, magnetic, and light. Fortunately, the boards and sensors are pretty affordable (Kubínová & Šlégr, 2015).

Inquiry-based learning 5E learning cycle

Inquiry-based learning is well known as an effective pedagogical approach for science subjects. 5E learning model, composed of 5 stages, i.e., engagement, exploration, explanation, elaboration, and evaluation, is one of the inquiry-based learning models used widely in science courses (Ruiz-Martín & Bybee, 2022). Table 1 explains each stage in the 5E learning cycle. Implementing the 5E learning model has improved the effectiveness of the teaching environment in a science course. It cultivates active research skills (Aşıksoy & Ozdamli, 2017) and enhances students' academic achievement (Hatice, 2016), creativity (Guven et al., 2022), and learning motivation (Cheng et al., 2016).

Table 1. Overview of 5E learning cycle stages (Hatice, 2016; Ong et al., 2021)

Stages	Description
Engagement	A stage where the lesson begins with an intriguing introduction provideing a situation for students to understand a problem they encounter. This stage connects students' prior knowledge to the new concept that they will learn
Exploration	Students conduct activities so that conceptual change can be facilitated. The activities may include experiments.
Explanation	Students are encouraged to describe what they have done and explain the result. In this stage, the teacher has an opportunity to introduce a concept, process, or skill.
Elaboration	Students are directed to apply the concept they have learned to a new situation
Evaluation	Students' understanding and acquired skills are assessed in this stage.

Online learning in Physics

The concept of distance learning has been well known for a long time ago. Distance learning refers to the learning process where teaching occurs differently from learning. Distance learning gives opportunities to students who have difficulty attending classes in person. The growth of internet technology has transformed the way of delivering knowledge. Online learning has become more popular as the internet has become more accessible.

Online learning is a form of distance learning where internet technology mediates the learning activity; teaching is delivered using the internet. With various online platforms available, direct communication among students and teachers during distance learning can be conducted easier (Pratama et al., 2020).

Besides the communication platform, a learning management system (LMS) also plays a role in optimizing online learning. Teachers can organize learning material, activities, and assessments through LMS. Students also can manage their learning plan with LMS. The study showed that LMS use has some positive impacts, like motivating students to work independently and improving the personalization of the learning process (Shurygin & Sabirova, 2017).

Teachers should not be limited to just transferring physics laws to students in physics courses. The scientific methodology should be introduced to students. Students should know how to apply scientific methods in physics. It will also help them develop abilities applicable in daily life (Organtini, 2018). For that reason, laboratory work should be incorporated into physics distance learning.

Facilitating hands-on practical work in distance learning is challenging since access to the laboratory is limited. It has become a concern for physics educators. Some alternatives such as simulation(Dark, 2021), pre-recorded video(Fox et al., 2021), live demonstration, and video modeling tools(Tiandho, 2021) have been used. However, some physics teachers are also disquieted by the lack of opportunities to train hands-on skills. Other options to support laboratory work during online learning is individual experiment project at home using smartphone sensors(Coramik & Ürek, 2021), Arduino board(Pratidhina et al., 2021), and home appliances (Dark, 2021).

Arduino

Arduino is an open-source platform that consists of electronic boards, sensors, expansion boards, and a software development environment. It is developed by Massimo Banzi and his team in Italy(Marzoli et al., 2021). The cost is relatively affordable and hence widely used for educational projects worldwide. Arduino Uno is the simplest and most used type of Arduino board.

Arduino Uno can be used to control devices and data logging. Arduino Uno can be connected to a computer through a USB connection; the users can program the Arduino Uno using free Integrated Development Environment software. The use of Arduino in physics courses also allows students to acquire additional competencies such as coding and programming (Organtini, 2018)

RESEARCH METHOD

Research model

A mixed research method is applied in this study, including both qualitative and quantitative data collection and analysis. In the quantitative dimension of the research, a one-group pre-test post-test design was used. Before implementing the learning model, a pre-test is given to investigate students' understanding of thermal physics. After students learn thermal physics within the 5E learning model, they are asked to do a post-test. To obtain students' perspectives on the implemented learning model, we asked students to make a short testimony about their learning experiences and perspective on it.

Participants

The research was conducted on a group of college students at a private university in Indonesia. Ten college students who majored in physics education participated in this study. They are second-and third-year college students who took a course called "Teaching High School Physics 2". The learning process was entirely online.

Instruments

The pre-and post-test is a two-tier test. The test comprises two-tier 20 items intended to assess students' understanding of thermal physics. The first tier is the multiple-choice type, and the second tier is a short essay type that asks the reason for the answer of the first tier. The score of pre- and post-test are compared by calculating the normalized-gain to determine the increase of students' conceptual understanding after the learning process. The normalized-gain is calculated by using equation (1).

$$n - gain = \frac{\%post - \%pre}{100 - \%pre} \quad (1)$$

Where, *%post* is the percentage of post-test score, *%pre* is the percentage of pre-test score.

At the end of learning sessions, students were asked to write a short essay to reflect on their learning process and give feedback on the learning strategy. The shot essay was analyzed qualitatively to collect the students' perspectives and evaluate the program.

FINDINGS AND DISCUSSION

Learning Activity

This study involves students who took the "Teaching High School Physics 2" course in the physics education department. The topic discussed in the learning process is thermal physics. The learning process is designed according to the 5E learning cycle and conducted online. The engagement, elaboration, and evaluation phases are conducted synchronously using zoom. Meanwhile, exploration and explanation are mainly conducted asynchronously, involving hands-on experiments using Arduino kits, documenting data analysis, and constructing explanations in the worksheet. Table 2 presents the description of each learning phase.

Table 2. The Learning Phases

Phase	Description	Mode (platform)
Week 1: Introduction to Arduino		
Pre-test	The pre-test is given to students before they participate in the learning process	Asynchronous (Moodle)
Introduction to Arduino	Students are introduced to Arduino	Asynchronous and Synchronous (Moodle and Zoom)
Week 2: Newton's Cooling Law		
Engagement	Students observed a stimulus video related to a cooling process. Students are asked to identify some research questions.	Synchronous (Zoom)
Exploration	Students conduct experiments using Arduino at home to investigate the cooling process of some types of liquids.	Asynchronous (Hands-on activity)
Explanation	Students analyze the data, present the temperature of liquids as a function of time in a graph, and describe the behavior of the cooling process. They are also asked to do a literature study and construct a mathematical model of temperature change during the cooling process.	Asynchronous (Moodle)
Elaboration	Students did a group discussion to solve some problems related to Newton's cooling law	Synchronous (Zoom)
Evaluation and reflection	Students reflected on their learning activity and encourage to summarize what they have learned.	Synchronous (Zoom)
Week 3: Phase Change Process		
Engagement	Students observed a stimulus video related to a phase change process. Students are asked to identify some research questions.	Synchronous (Zoom)

Exploration	Students conducted an experiment using Arduino at home to investigate the temperature of hot liquid stearic acid is cooled until its phase change to solid.	Asynchronous (Hands-on activity)
Explanation	Students analyzed the data, present the temperature of liquids as a function of time in a graph, and describe the temperature trend during the phase change process. They are also asked to do a literature study and identify the energy released during phase change	Asynchronous (Moodle)
Elaboration	Students did a group discussion to solve some problems related to phase change	Synchronous (Zoom)
Evaluation	Students reflected on their learning activity and were encouraged to summarize what they have learned.	Synchronous (Zoom)
Week 4: Post-test		
Post-test	After the implementation of the learning model, students were asked to do a post-test and write a journal about their experience and perspective on the learning process.	Asynchronous (Moodle)

In the exploration phase, students performed physics experiments using Arduino at home. There were two experiments, i.e., Newton's Cooling Law and Stearic Acid Phase Change experiments. Figure 1 shows Newton's cooling law experiments by one of the students. This experiment aims to model the relation between the rate of heat loss from a body and the body-environment temperature gap. Figure 2 shows an experiment about freezing stearic acid phase change of stearic acid conducted by a student at home. In this experiment, students could observe the melting and freezing points of a material and plot a graph.

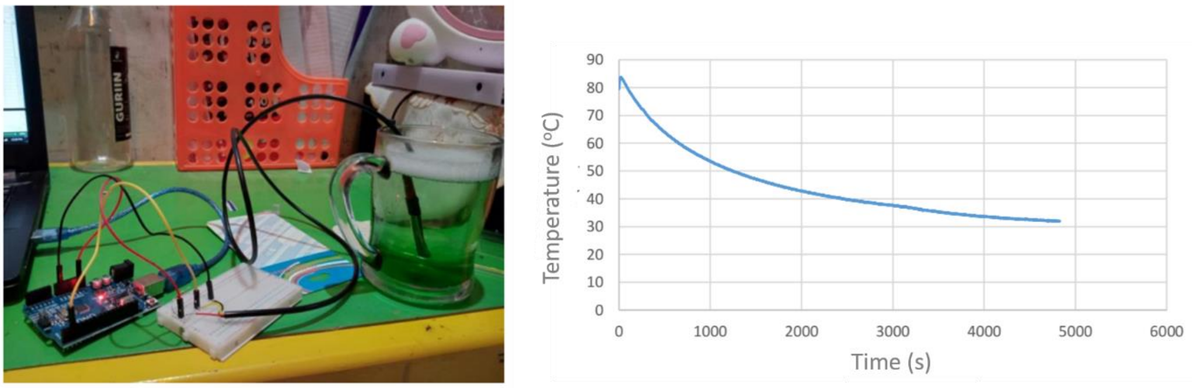

Figure 1. Documentation of Newton's Cooling Law conducted by a student at home

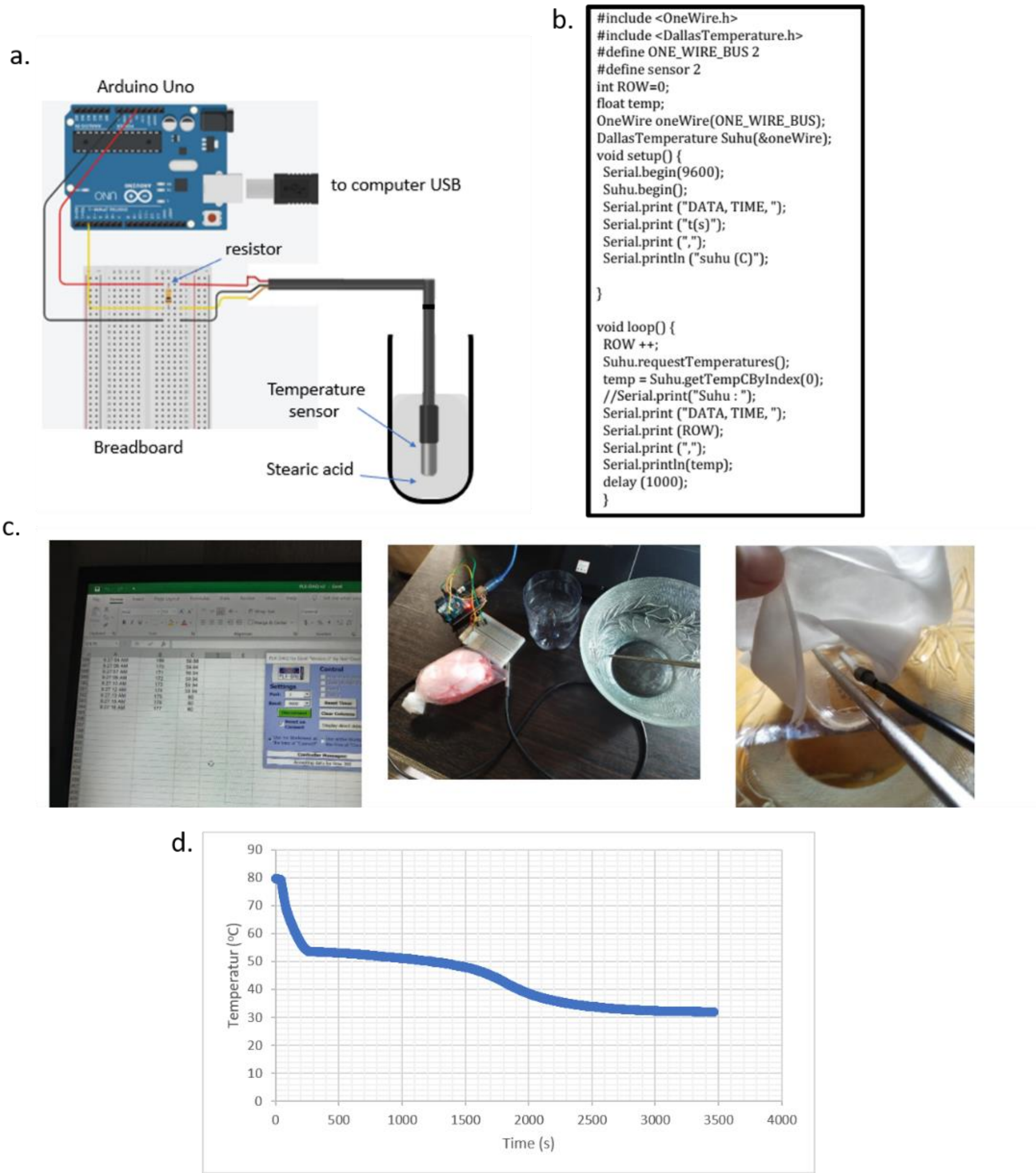

Figure 2. (a) The set-up of phase change experiment using Arduino, (b) The script to program Arduino and temperature sensor, (c) Experiment conducted by a student, and (d) The temperature change during cooling hot stearic acid.

Effect of the implementation of the learning model on students' conceptual understanding

Before and after students were exposed to the 5E learning cycle assisted with Arduino, students were asked to do pre-and post-test. Table 3 shows the pre-test and post-test score of each student. All students gained their scores after the learning process. According to the N-gain calculation, four students achieved a high N-gain, five students obtained a medium N-gain, and one student obtained a low N-gain. The class average improved from 31.3 to 69.6, with an average N-gain of 0.56. Hence, on average, students who participated in this study achieved medium N-gain.

Table 3 Comparison between pre-test and post-test scores

Students	Pre-test score (max=100)	Post-test score (max=100)	N-gain	criteria
S1	28	60	0.44	medium
S2	28	61	0.46	medium
S3	23	59	0.47	medium
S4	21	60	0.49	medium
S5	30	35	0.07	low
S6	35	91	0.86	high
S7	60	79	0.48	medium
S8	31	85	0.78	high
S9	29	86	0.80	high
S10	28	80	0.72	high
Average	31.3	69.6	0.56	medium

Students Perception

At the end of the learning activity, students were asked to write their testimony in a short essay (see Table 4). Students mentioned that they have opportunities to improve their practical skills and understanding of physics concepts. Moreover, they could widen their insight into pedagogical approaches in online physics learning that can be applied to their future physics teaching career.

Some students in the second year had not conducted hands-on experimental work before due to COVID-19 restrictions. During COVID-19 restriction, a laboratory-based course was transformed using simulation and live demonstration. Hence, this is the first time conducting hands-on experiments in college for some students. Some students express excitement when they can observe physics phenomena directly by doing experiments at home. However, they also experienced some problems, such as finding some errors in the program. Arduino and programing are something new for them. Teachers still need to monitor their projects regularly and arrange consultation sessions for students who need additional guidance. Students also highlight that the presence of group mates has advantages to exchanging ideas and helping each other finish the projects. Another problem that they mentioned is the unconducive home situation.

Table 4. Students' testimony (English translation)

Student	Testimony
S1	Arduino is not something new for me. However, this is the first time I have used Arduino in a physics experiment. In this project, I learn how to collect and analyze data. At first, I found some obstacles during data analysis, especially when dealing with graph equations. Fortunately, my groupmate helped me to use Ms. Excel. In this course, I can realize that physics is not only composed of theory but also a practical thing.
S2	The learning activities help me acquire practical skills; I learn how to set up the experiment and program the Arduino. I can see physics phenomena directly, such as the phase change of stearic acid. Moreover, this kind of learning model gives me an insight into how to facilitate my future students with various activities, especially in online learning.
S3	We got experience in modeling the cooling process of material and observing the phase change of stearic acid. After the activities, I can better understand the temperature and phase change of a material. When experimenting, there is no significant problem because the teacher has provided helpful tutorial videos and worksheets.
S4	Through the experimental project, I can directly observe the phase change process. I also can practice how to use experimental apparatus at home. The video provided by the teacher was helpful for me

	in doing the project. The obstacle that I faced during online learning is sometimes it is difficult to get focused because the situation at home is noisy. For my future career, this kind of project will be beneficial. As science teachers, we have to master hands-on activities to provide various learning experiences for our students.
S5	I learned many concepts in thermal physics, such as temperature change, latent heat, heat transfer, internal energy, etc. Doing the experimental project at home was a challenge for me. I think I am not a typical student with strong mathematical skills and academic performance; I relatively need longer time to understand the material and do the assignment. Fortunately, the lecturer provided a pre-recorded video to support students in doing the experimental project. It is beneficial for me.
S6	I think the way learning thermal physics through experiment projects will be helpful for my future career. When I become a teacher, I will encourage students to learn physics through inquiry and collaborate with their peers.
S7	Besides learning thermal physics, I also have the opportunity to conduct an experiment and use Arduino. I can practice programming Arduino and use it for a physics experiment.
S8	We are well facilitated during the online learning. We received an experimental kit and experimented with it. I face several problems when doing the experimental project. However, through discussions with my group mate and teacher, I can get the solution and finish the project well.
S9	I appreciate the teacher who tried to facilitate the learning process by sending experiment kits to students during the online learning. I can improve my experimental skills and understand the physical process with the experimental project. I found some errors during the experiment, but I could not directly ask the teacher because I experimented at night. However, the next day, I could discuss it with my teacher through WhatsApp, and I could solve the problem.
S10	The teacher sends us an experimental kit to facilitate laboratory work during the school-from-home period. It is an excellent way to train students' experimental skills when we have to maintain social distance.

Overall, the results of this study indicate that the 5E learning model, which assisted with home experiments using Arduino, is promising for developing students' conceptual understanding. This result is aligned with previous studies that found that an inquiry approach in physics learning tends to improve the understanding of physics concepts compared with conventional learning. In an inquiry environment, students have more opportunities to construct concepts independently through problem presentation, hypothesis making, data collection, and analysis (Maknun, 2020; Tsivitanidou et al., 2021). The inquiry environment is also built into the 5E learning model. In addition, the use of Arduino supports students to experiment at home so that they have chances to collect and analyze data comprehensively. In this study, the implementation of Arduino technology has also gained students' interest, which is also shown in other studies (Chaudry, 2020). Even though this study is conducted with a small scope, the initial findings indicate that the 5E learning model with Arduino is promising for improving the quality of physics learning.

CONCLUSION

Transforming laboratory work into a distance learning mode is challenging. This study attempted to design a 5E learning cycle incorporating an Arduino-based experiment conducted at home. The initial findings of this study show that the developed learning model is promising. According to our research, students' understanding of thermal physics improves with an N-gain of 0.56 after exposure to the online 5E learning cycle. Students felt several advantages: they can enhance practical skills, deepen their understanding of physics concepts, and widen their insight on the pedagogical approach in physics online learning. However, because Arduino is still new to most students, they found it difficult to use during the first trial. Hence, the lecturer provides additional guidance. There are some limitations to this study. In the future, the study can be conducted more comprehensively by increasing the number of participants involved in the implementation and exploring the impact of the learning process on improving various students' competencies.

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