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Fluid Learning with Arduino-Based on Engineering Design Process (EDP) to Improve Student's Problem-Solving Ability

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This study aims to obtain an overview of physics learning on the topic of fluid material with an Arduino-based engineering design process (EDP) to improve students' problem-solving abilities. This study used a quasi-experimental research method with a pretest-posttest control group design. The subjects in this study were students of class XI MIPA by taking two groups of subjects using a purposive sampling technique. The sample for the experimental class was 36 people and the control class was 36 people, so the total number of research subjects was 72 people. The learning implementation instrument was carried out using an observation sheet. The results of the ability to solve problems are measured using a description test which includes indicators of problem-solving abilities. Student responses using a Likert scale. The results of the data analysis showed that the average N-Gain achievement was in the medium category and the results of the independent test showed a significant difference in increasing problem-solving skills. Most of the students gave positive responses to learning with Arduino-based EDP, felt happy and motivated, provided benefits, every process undertaken by students provided challenges in solving the problems they faced so that fluid learning using the Arduino-based engineering design process (EDP) stages was able to improve students' ability to solve problems.

1. Introduction

The era of the Industrial Revolution 4.0 is an educational challenge in preparing learning systems that are more innovative, and able to increase the competence of graduates who have 21st-century skills (Dewi et al., 2021; Redhana, 2019). Ability to adapt and manage complexity, be self-directed, be curious, ready to take risks, high-order thinking, and sound reasoning are skills that must be possessed in the 21st-century skills (Lemke, 2002). Learning and innovation skills include creativity and innovation, critical thinking and problem-solving, and communication and collaboration (Malik & Ubaidillah, 2020; Malik et al., 2021). Mastery of problem-solving skills includes the skills of identifying, searching, selecting, evaluating, organizing, considering various alternatives, and interpreting information needed for teamwork, effective, and creative collaboration in innovation (Szabo et al., 2020). The reality in the field of science learning by showing the ability to solve problems is not optimal. The 2018 PISA results experienced a decrease from 2015 in terms of reading ability, math, and science performance (Tohir & Ibrahimy, 2020). Practicing problem-solving skills in learning can be done with a learning model that is centered on student activity and constructivism principles. This approach gives students the freedom to explore their own knowledge in order to obtain in-depth knowledge and improve its quality (Antika, 2014). The principle of constructivism is able to encourage students as learners to be able to solve new problems, assist students in integrating new knowledge, and motivate students as learners to create new knowledge for themselves (Mohiddin, 2016).

Problem-solving includes basic skills or life skills. In problem-solving, there are creative steps that are needed by looking at the qualities of fluency, flexibility, and originality (Guilford, 1957). Problem-solving skills are actions in solving-problems or processes by utilizing the mathematics and knowledge they have and finding solutions through the stages of problem-solving. This activity can be used as a preparation for 21st-century learning which requires students to have the ability to solve problems (Hidayat et al., 2017). Research conducted by Mustofa & Rusdiana (2016) shows that the average presentation score of problem-solving abilities is unsatisfactory. The lack of students' problem-solving abilities can be overcome by providing innovative learning methods, which are expected to help students practice 21st-century skills. One learning approach that can contribute to students is STEM learning. STEM-EDP learning is used as a learning tool, promoting student progress and the level of self-efficacy (curiosity/motivation to make oneself superior or better) (Carberry, Lee, & Ohland, 2010).

The STEM learning approach aims to develop thinking, reasoning, teamwork, investigation, and creative skills that students can use in all areas of their lives (Jolly, 2016). The integration of the Engineering Design Process (EDP) in STEM learning with the inquiry process is able to produce an understanding of science concepts and other learning products, namely innovation and creative products. This learning can be done through problem-based learning and projects (Grubbs, M., & Strimel, 2015). EDP is able to provide opportunities for students to solve problems in science content related to real life, as well as introduce students to the field of engineering (Berland, Steingut, & Ko, 2014). This teaching and learning approach is able to help students relate the material taught to students' real-world situations and encourage students to make connections between the knowledge they have and its application in their lives as members of their families and communities (Keiler, 2018).

Some of the characteristics of STEM learning, including (1) focusing on the real world, (2) can be integrated with the engineering design process (EDP) which is able to lead students to identify problems or challenge students in designing and developing solutions, (3) being able to provide student learning experiences in investigation and exploration, (4) involving students working in productive teams, (5) being able to bring students to make creative solutions in solving problems (Ejiwale, 2012). The design process series of activities begins with imagining and exchanging ideas, being creative in investigating the technology and methods used, exploring, comparing, and analyzing solutions then proceeding with choosing a design according to needs, planning by drawing ideas and how it works, considering the materials and tools needed by analyzing the advantages and disadvantages and discussing to improve and improve product quality (Tayal & Gupta, 2013). Opportunities in providing student learning experiences so that students are able to construct knowledge in their cognitive processes and can understand and apply the knowledge they have (Ariandi, 2014)

The results of a survey that was conducted on 70 science teachers, learning using Arduino-based EDP stages is still rarely used, and science teachers believe Arduino learning can be applied in material and believe it can improve students' problem-solving skills. Arduino is a familiar platform in physics education and teaching. With a relatively low cost, it can provide a learning experience for students (Winarno, 2020). Based on the description above, it is necessary to have a student-centered learning design and constructivism that leads to increasing the capacity of science learners to build their own knowledge and improve old knowledge. EDP-based science learning can be developed using media so that it involves students more intensely, is more interactive, and is able to develop awareness of creative and adapting to change the world (Vandeleur, 2001). Arduino integration in learning is rarely used, so this research will discuss how to implement Arduino-based EDP in solving students' problems in physics material about fluids.

2. Method

This study used a quasi-experimental method with a pretest-posttest control group design, which was conducted at a high school in Bogor. The population of this study was 72 students, which were divided into 2 class groups, namely 36 students in the control class and 36 students in the experimental class. The data collection technique used was purposive sampling, which was taken not randomly but was determined by the researcher with certain considerations. The instruments used were test and non-test instruments. The test instruments are in the form of problem-solving ability test sheets (description questions) and student worksheets (LKPD). This instrument contains questions which that are indicators of the stages of problem-solving, namely a) focusing on problems, B) describing problems, c) designing solutions, d) realizing designs that are adjusted to planning, e) evaluating answers (Heller & Heller, 2010). While the non-test instruments are in the form of observation sheets about the implementation of learning based on the EDP stages (define the problem, research, imagine, plan, create, test and evaluate, redesign and communicate) (Jolly, 2016), and student response questionnaires after learning.

The results of the validity and reliability tests of this study are valid and reliable. The test results are said to be valid and reliable if the r-count > r-table. The r-count value obtained from the 5% significance table with a total of 36 data is 0.329. The average value of r-count from the results of the validity test is 0.539 while the results of the reliability test obtained a value of 0.767. Both of these values show greater than r-table, meaning that they are declared valid and reliable. After testing the validity and reliability, then the research was carried out in the control class and the experimental class. Data obtained from research results in the form of problem-solving ability tests (pre-test and post-test), were analyzed until the N-Gain value was obtained to determine an increase in problem-solving ability. N-Gain with a value of more than 0.7 is in the high category, between 0.3 – 0.7 is in the moderate category, and less than 0.3 is in the low category (Meltzer, 2002). The data analysis technique in the prerequisite test is in the form of a normality test using the Shapiro-Wilk test (N <100) and the homogeneity test of variance. The resulting data were analyzed using parametric statistics with the t-test between groups (independent-test) if the data were normally distributed and the variance between groups was homogeneous.

3. Result and Discussion

The fluid learning process using Arduino-based EDP stages has shown an increase in students' problem-solving skills. The EDP stages that students go through consist of define the problem, research, imagine, plan, create, test and evaluate, redesign, and communicate (Jolly, 2016). The EDP stages fulfill the criteria in bringing out problem-solving skills for students. Each stage of EDP students are required to find solutions regarding various real products (Hafiz & Ayop, 2019). Physics which is considered difficult in mastering concepts, learning through the STEM-EDP approach can be the right solution to explore students' ability to solve problems (Sya'roni, Putri, & Devianti, 2021). This learning is done with the help of peer tutors who act as observers in integrating Arduino into the designs that have been made. Each student begins by doing a pretest to find out the initial conceptual understanding of the material being studied. Furthermore, during the study, observations were made by the observer. Students work in small collaborative groups to solve problems and the teacher acts as a facilitator in guiding students in the learning cycle (Hmelo-Silver, 2004). Student problem-solving in developing relevant critical thinking skills can be fostered through group discussions (Chan, 2012). Practicing problem-solving helps students make connections between theory and real-world applications and develops their ability to deal with the complexity of real-world problems in small groups with instructor guidance (Hung, 2012).

Collaborative learning shows the interaction between teams, including sharing something to achieve goals, giving each other more in-depth input and solutions, asking each other questions and reacting to each other, working in understanding each other, and jointly being accountable for their results (Apriyono, 2013). Collaborative activities at the EDP stage are shown by the percentage value of 62% at the create stage and 70% at the redesign stage. This shows that collaboration in working on prototypes has been able to help students solve problems. Overall, the percentage of observations of the implementation of learning is presented in Table 1.

Table 1. Percentage of observation results of learning implementation

No	EDP Stage	Percentage (%)	
		Yes	No
1	Define the problem	61	39
2	Research	54	46
3	Imagine	39	61
4	Plan	58	42
5	Create	62	38
6	Test and evaluate	59	41
7	Redesign	70	30
8	Communicate	95	5

EDP stages are carried out in 2 activities, namely individuals and groups. The EDP stages which consist of defining the problem, researching, and imagining are carried out individually. This stage describes a series of activities starting from raising problems, raising questions related to problems, formulating problems, finding sources and references to use, gathering information, imagining the results of their thoughts in the form of images, and creating creative out-of-the-box ideas. The EDP (define the problem and research) stage shows that most students have been able to find problems and find sources in gathering information, while the EDP (Imagine) stage shows that students' ability when imagining what is obtained into a simple picture is very low, namely only 39%. This proves that students' creative ideas have not been seen and still need practice so that students get used to them. The next EDP stage is the EDP stage which is carried out in groups/collaboration consisting of plan, create, test and evaluate, redesign, and communicate. This EDP stage shows the ability of students in group discussions. The development of social and collaborative skills is considered something natural and does not require more facilities. (Hesse, Care, Buder, Sassenberg, & Griffi, 2015) Activities at this stage include planning by selecting the best prototype ideas in groups, designing prototypes , testing prototypes together and communicating. Each stage of EDP requires students to find solutions to real products, including in the form of product designs in the form of robots, children's toys, modeling houses, planes, miniature tools, or Lego (Hafiz & Ayop, 2019).

The results of the instrument analysis in the form of pre-test and post-test answers from the experimental class and the control class showed that the N-Gain value was in the moderate category. The results of the pre-test and post-test of the control and experimental classes are presented in table 5 which shows a comparison of the mean pretest, posttest, and N-gain scores of students' problem-solving abilities.

Table 2. Comparison of the mean pretest, posttest, and N-Gain students' problem-solving ability

Class	Average Score			Category
	Pretest	Posttest	N-Gain (%)	
Experiment	28.11	65.47	51.32	Medium
Control	24.36	59.08	46.85	Medium

Table 2 show that the mean pretest values for the experimental and control classes were relatively the same, namely 28.11 and 24.36. After being given treatment using the Arduino-based EDP stages, there was a significant change, in the experimental class it was 65.47 with an N-gain of 51.32%. while in the control class it was 59.08 with an N-gain of 46.85%, both of which were in the medium category. From the data from the pretest and posttest results, normality and homogeneity tests were carried out to determine the significance value for the learning outcomes of the experimental class and the control class. The sample data used is less than 50, so the significance test value used is Shapiro Wilk. The normality test results using Shapiro Wilk obtained the pretest and posttest results of 0.358 and 0.599 for the control class, while for the experimental class the pretest and posttest results were 0.108 and 0.060. The data is presented in Table 3.

Table 3. Pretest and posttest value normality test results

Data	Class	N	Mean	Kolmogorov Smirnov Sig.	Shapiro Wilk Sig.	α
Pretest	Experiment	36	28.11	0.200	0.108	0,05
	Control	36	24.36	0.047	0.358	
Posttest	Experiment	36	65.47	0.095	0.060	
	Control	36	59.08	0.200	0.599	

The results of the significance test using Shapiro Wilk obtained a significance value of > 0.05 which indicates that the data is normally distributed. After carrying out the normality test, then the homogeneity test was carried out. The results of the homogeneity test for learning outcomes are seen from the posttest scores. The homogeneity test is said to be homogeneous if the data obtained has a significance value of > 0.05. The results of the homogeneity test data for learning outcomes show that homogeneous data is obtained from the results presented in Table 4.

Table 4. Pretest and posttest value homogeneity test results

Data	Class	N	Mean	Sig.	α
Pretestt	Experiment	36	28.11	0.003	0,05
	Control	36	24.36		
Posttest	Experiment	36	65.47	0.053	
	Control	36	59.08		

After the normality and homogeneity tests were carried out which stated that the data was normal and homogeneous, then the independent test was continued. The independent test was chosen because the prerequisite test had been fulfilled, namely normal and homogeneous data. The independent test was used to see whether the given Arduino-based EDP stages were able to improve problem solving abilities. The independent test results from the pretest and posttest results obtained significance test values that look different. The test results are said to be significantly different if the sig (2-tailed) value on the independent test is < 0.05. Table 8 shows the significance test value after being given treatment is 0.043. This shows a sig value (2-tailed) < 0.05 which indicates a significant difference. The results of this significant difference indicate an increase in ability to solve problems in this case fluid learning using Arduino-based EDP stages. This learning has trained students and provided learning experiences (Vandeleur, 2001). Learning by integrating EDP can lead to better problem-solving skills (Syukri, 2018).

Table 5. Independent Test Results for Pretest and Posttest Results

Data	Class	N	Mean	Sig (2-tailed)	α	Conclusion
Pretest	Experiment	36	28.11	0.166	0,05	Not significantly different
	Control	36	24.36			
Posttest	Experiment	36	65.47	0.043		Significantly different
	Control	36	59.08			

Apart from the learning outcomes of pretest and posttest scores, from the results of this study a survey was conducted on student responses consisting of motivation, usefulness or significance, ability to design models, challenges, and expectations. The results of student responses in this study are presented in Table 6.

Tabel 6. Student' response results

No	Indicator	Percentage (%)
1	Motivation	81
2	Use/benefits	81
3	Designing ability	60
4	Challenges	80
5	Hope	85

Learning physics by developing problem-solving skills can stimulate students towards constructive, and contextual learning, realistic problems in accordance with previous knowledge and skills. This is shown through the results of student responses showed that 81% of students were very motivated to gain new knowledge, new learning so that 81% of students considered this activity to provide its own benefits and a meaningful learning experience. The prototype design concept and the ability to integrate Arduino show that 80% of students feel challenged so that 85% of students have good expectations in this lesson, even though the ability to design is only around 60%, it is necessary to have continuous learning so that students are increasingly trained to come up with ideas creative and create solutions. This student response shows that this learning is very applicable in everyday life, Arduino-based EDP activities can be used as a strategy to improve problem-solving skills, have a positive impact on finding students who have increased quite quickly and have high belief motivation about science (Hafiz & Ayop, 2019). Student responses to aspects of EDP, including prototyping, structural design and collaboration are able to contribute to training students' creative thinking skills (Zhou et al., 2017). In addition, there is an increase in teacher-student interaction in STEM learning collaboration and an increase in motivation can be used as a knowledge base for students and the development of life-long learning skills (Asunda & Walker, 2019).

4. Conclusion

The implementation of physics learning on fluid material using Arduino-based EDP learning has been able to improve students' problem solving abilities. The abilities that must be possessed at this stage are in accordance with the challenges of 21st century learning. Each EDP stage carried out by students is able to provide a learning experience. The more complicated the prototype design, the more difficult it will be to integrate Arduino into the design so that it takes quite a long time to do this prototype design to get perfect results. The results of the pretest and posttest conducted before and after learning showed significant differences. From this difference it shows that learning physics with Arduino-based EDP can improve students' problem solving abilities. In addition, student responses gave positive responses to Arduino-based EDP learning on fluid material. Further research can be carried out in order to obtain maximum learning results, physics learning with Arduino-based EDP can be used on other physics material so that students' problem-solving ability levels are more trained. increase imagination in associating concepts with contextual problems

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