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STUDENTS' PROBLEM-SOLVING SKILLS IN ARCHIMEDES' PRINCIPLE BASED ON A PROJECT-BASED LEARNING MODEL

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Abstract

We carried out a study to improve students' problem-solving skills through project-based learning (PjBL) on Archimedes' principle material. Subjects consisting of 29 students were randomly selected to take part in learning with a one-group pre-test post-test design. Data analysis used t-test analysis. The research results showed that there was an increase in students' problem-solving skills on the indicators of acceptance, problem, and fact findings, however the low increasing on idea, and solution findings. The T-test analysis result shows a significant difference in the average scores of the pre-test and post-test. This shows that the implementation of PjBL on Archimedes' principle material can improve students' problem-solving skills. Although in general, project-based learning can improve students' problem-solving skills, this study is not optimal, especially on idea and solution findings. The weakness of this research is that it was only carried out in two meetings. This study can be implemented into further project-based learning in several cycles to make the problem-solving skills to be more trained well.

Keywords: Archimedes' principle, Learning quality, Physics learning, Problem-solving skills, Project-based learning.

1. Introduction

Exploring students' problem-solving skills in the context of Archimedes' Principle through a project-based learning (PjBL) model provides valuable insights into educational methodologies that enhance cognitive abilities and practical understanding. PjBL emphasizes active learning, where students engage in hands-on projects that require them to apply theoretical knowledge to real-world problems. Recent research shows that PjBL is highly effective in science education because it fosters critical thinking, collaboration, and the application of scientific concepts in practical scenarios [1-3]. Studies indicate that PjBL enhances students' problem-solving skills by promoting a deeper understanding of the subject matter.

PjBL can improve students' problem-solving skills by encouraging greater cognitive flexibility. This cognitive flexibility allows students to approach problems from various perspectives and apply multiple strategies to find solutions [4, 5]. In the context of Archimedes' Principle, where understanding buoyancy and fluid dynamics requires not only theoretical knowledge but also the ability to apply this knowledge in practical experiments, PjBL has proven effective. The integration of spatial reasoning skills further supports this, as students must visualize and manipulate three-dimensional objects to grasp the principles involved [6]. PjBL implementation also shows an increase in student engagement and motivation, which are critical for effective learning. By participating in collaborative projects, students are encouraged to take responsibility for their learning, leading to increased autonomy and a sense of responsibility for their educational outcomes [7, 8]. However, the effectiveness of PjBL can vary depending on students' initial skill levels and specific learning environments, with some studies indicating that certain students might struggle with group dynamics or may not fully engage in discussions, potentially hindering their learning experience [9].

To train problem-solving skills to students, of course, it must be adjusted to the learning model used. Relevant research explains that to be able to train problem-solving skills, you can use the PjBL model [10]. The PjBL model requires students to be able to understand the problems they are facing and try to solve these problems with products made either independently or in groups to make students more active in the learning process, providing students with the readiness to be able to face problems in real life. Thus, it encourages students to be interactive during the learning process and encourages students to be more creative individually with their surroundings [11-17]. This model can train problem-solving skills that enable students to practice 21st-century skills such as creativity, collaboration, communication, and technological skills that can be used to solve problems in real life [18-22].

This study aims to explore students' problem-solving skills in the context of Archimedes' Principle through the application of a PjBL model. The focus is on how PjBL can enhance students' understanding of fundamental concepts of buoyancy and fluid dynamics and how these skills are applied in practical projects. The scope of the study includes analyzing the impact of PjBL on problem-solving and collaboration skills in science education. To be able to train students' problem-solving skills on Archimedes' principle material well, indeed, a good design of each activity or learning strategy is needed to provide treatment to students in the learning process. Thus, we used the PjBL model, because that is appropriate for physics learning [23, 24].

The novelty of this study lies in the specific application of the PjBL model to teaching Archimedes' Principle, an approach that has not been widely explored in this context. This study not only tests the effectiveness of PjBL in improving theoretical understanding but also evaluates how this model affects practical and cognitive skills in buoyancy-based experiments. Thus, the study provides new insights into how PjBL can be more effectively applied in science education. The problem-solving skills of students are trained based on The Osborn Parnes theory which focuses on creative problem solving, which consists of several main stages, namely objective finding, fact-finding, problem finding, idea finding, solution finding, and acceptance finding [25-27]. Static fluid material related to Archimedes' principle. This material is suitable for use because it is the basic material that is closely related to everyday life. Thus, it will make students think more and be able to find problems and be able to solve them with the concepts and theories that will be studied [28-30].

The hypothesis that PjBL enhances students' problem-solving skills in the context of Archimedes' Principle is based on evidence that active learning and the application of theory in practical projects improve deep understanding and cognitive flexibility. Research shows that students involved in PjBL can tackle challenges and solve problems more effectively because they learn to view issues from various angles and employ multiple strategies. Additionally, increased motivation and engagement in collaborative projects contribute to the development of better problem-solving skills.

2. Literature Review

2.1. Archimedes' Principle

Archimedes' principle is one of the most essential laws of physics and fluid mechanics. The principle states an object immersed in a fluid is buoyed up by a force equal to the weight of the fluid that it displaces. This principle, which is perhaps the most fundamental law in hydrostatics, explains many natural phenomena from both qualitative and quantitative points of view [31]. Derivation of Archimedes' Principle based on the variation of hydrostatic pressure Pf as a function of depth of the fluid, $Pf=Dfgy$, where Df is density of the fluid, y is the depth, and g is the acceleration due to gravity. In this approach, an object of simple geometry such as a rectangular or cylindrical block is considered and the net fluid force due to the difference of hydrostatic pressure at the top and the bottom of the block is calculated.

Consider a fluid of density Df and an object of arbitrary shape of mass m and volume V, denser than the fluid. The fluid is in a container of cross-sectional area A and has a height H before the object enters it. The object is supported by a string and, at this time, the tension in the string is mg. Because fluid forces on the side walls of the container cancel, before the object enters the fluid, the net force F exerted by the fluid on the container is only due to the hydrostatic pressure at the bottom of the container, which is given by $F=DfgHA$, when we lower the object down into the fluid until it is submerged. This causes the height of the fluid in the container to increase by δH, where δH is given by $\delta H=VA$.

Therefore, the net fluid force on the bottom of the container increases by δF, which is given by $\delta F=Dfg\delta HA=DfgV$, which is exactly equal to the weight of the fluid displaced. Therefore, when the object enters the fluid, the level of the fluid increases, and the container experiences an additional downward fluid force equal to the weight of the fluid displaced by the object. The upward force from the container-fluid system which is equal to the weight of the fluid displaced, $DfgV$. Consequently, the tension in the string would each be given by $F=mg-DfgV$, which is exactly the apparent weight of the object. Figure 1 explains the difference in density causing objects to sink or float or float.

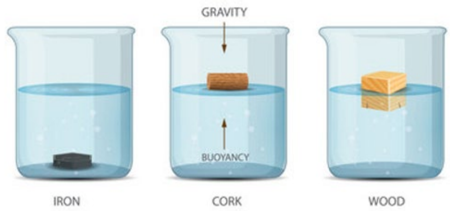

Fig. 1. The difference in density causes floating objects to float and sink.

One of the applications of Archimedes' Principle was on Pontoon Bridges. There are two types of this bridge, namely pontoon foundations and pontoon girders Pontoon foundations is a separated pontoon bridges whereas the pontoon girders a continuous pontoon bridges. Figure 2 explains the application of Archimedes' principle to Pontoon Bridges [32].

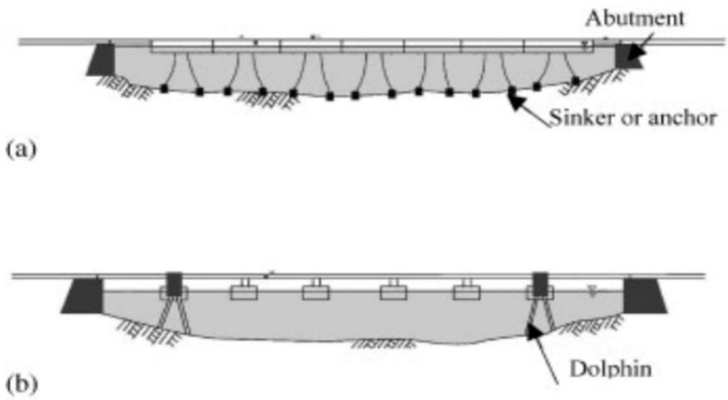

Fig. 2. Floating bridge; (a) pontoon girders, (b) pontoon foundation.

In an emergency, a pontoon bridge can be made by installing several tightly closed empty drums in a row and placing planks on top for people to walk on. The empty drums will float in the water because they have cavities filled with air inside. That way, the density of the drum is smaller than the density of water. So, the pontoon bridge can float. A pontoon bridge is a floating bridge that is supported by a kind of pontoon to support the bridge foundation and the dynamic load above it. Pontoon bridges are usually temporary structures, although some are used for a long period. Permanent floating bridges are very useful for crossing waters where it is considered uneconomical to build a bridge suspended from a pier. Such bridges can have a raised or liftable section, for the passage of ships.

2.2. Project-Based Learning (PjBL)

PjBL is an application of learning that focuses on students building knowledge independently and being able to demonstrate new understanding obtained with various forms of representation [33, 34]. In its implementation, educators will become facilitators and managers of project learning. Students are required to be able to play an active role in the learning process, will be faced with real problems and can work individually or in groups and will be carried out within a certain period [35, 36]. The main problem in PjBL is a real-life problem and is open-ended, which means that the problem must be able to be solved practically and in an unstructured manner.

The use of the PjBL Learning model will have greater potential to provide a more interesting and meaningful learning experience for students. PjBL itself has several characteristics, namely: (i) students make decisions and create frameworks, (ii) there are problems whose solutions have not been found before, (iii) students design the process to achieve results, (iv) students are responsible for obtaining and managing the information that has been collected, (v) students carry out continuous evaluations, (vi) students regularly review what students do, and (vii) the final results of learning in the form of products and their quality are evaluated. The purpose of the PjBL learning model is to provide students with the ability to obtain more efficient learning and knowledge [37-39]. Other previous studies about PjBL are shown in Table 1.

2.3. Students' Problem-Solving Skills

Problem-solving skills are the main goal in learning because problem-solving is a cognitive activity involved in the learning process and this skill is related to aspects of knowledge, thinking skills, and reasoning abilities. Problem-solving skills include a person's ability to use cognitive processing to understand and solve a problem, even when the method is not clear [40]. Problem-solving skills are essential in the 21st century. Evaluation of students' problem-solving skills aims to measure their readiness to face the challenges of this era. These skills are key to creating innovative solutions to global problems, both those that exist today and those that may arise in the future [41, 42]. In this skill, the problems given to students are real problems. Thus, they will be able to train 21st-century skills. The five-step creative problem-solving process was developed with the educational purpose of enabling students to develop their creativity [43, 44]. This five-stage process was used in a range of education programs in the US and became known as the Osborn-Parnes creative problem-solving model. Table 2 serve other previous studies about students' problem-solving skills.

3. Method

This study used a quantitative descriptive approach, with a one-group pre-test-post-test design. The research subjects were 29 students in the 11th grade of senior high school, who consisted of 18 males and 11 females. Data analysis used paired sample t-test, summary data statistic and wright map. The hypothesis that PjBL enhances students' problem-solving skills in the context of Archimedes' Principle is based on evidence that active learning and the application of theory in practical projects improve deep understanding and cognitive flexibility. Data was also calculated using SPSS [45].

Table 1. Previous studies about PjBL.

No.	Title	Ref.
1	Problem-based learning (PBL) and project-based learning (PjBL) in a continuously improving chemical engineering laboratory experience.	[46]
2	Critical thinking and collaboration skills on environmental awareness in project-based science learning	[47]
3	A model for incorporating information literacy and collaboration in a project-based learning pedagogical exercise with application to a fluid mechanics course	[48]
4	Developing stem project-based learning module for primary school teachers: a need analysis	[49]
5	The influence of project-based learning and problem-based learning models on science learning ability from the perspectives of learning interest: project based learning and problem based learning	[50]
6	Effectiveness of project-based mathematics in first-year high school in terms of learning environment and student outcomes	[51]
7	The effectiveness of integrated science, technology, engineering and mathematics project-based learning module	[52]
8	The effects of project-based learning on student behavior and teacher burnout in an emotional/behavioral support classroom	[53]
9	Developing a project-based learning course model combined with the think–pair–share strategy to enhance creative thinking skills in education students	[54]
10	The impact of a combination of flipped classroom and project-based learning on the learning motivation of university students	[55]
11	Temperature distribution in bio stove using saw dust: An integrated project-based learning	[56]
12	Technology-supported project-based learning: trends, review and future research in science, technology and engineering education	[57]
13	Profile of communication skills of students in groups with the application of blended learning using project-based learning model	[58]
14	Interactive multimedia design of motion graphics using a project-based learning approach for vocational education students: experiments in cooking Taliwang chicken	[59]
15	Student development: implementation of water rocket media as a project-based learning tool to improve the literacy of junior high school students during the pandemic	[60]
16	Application of project-based worksheets for making conditioner from aloe vera (aloe vera l.) to develop students' scientific performance	[61]
17	Implementing project-based worksheets on making kaolin soap with the addition of kefir curd to develop students' scientific performance in islamic school	[62]

Table 2. Previous studies about students' problem-solving skills.

No.	Title	Ref.
1	Evaluating metacognitive strategies and self-regulated learning to predict primary school students' self-efficacy and problem-solving skills in science learning	[63]
2	Problem-solving skills of high school students in chemistry.	[64]
3	Studying the student's perceptions of engagement and problem-solving skills for academic achievement in chemistry at the higher secondary level.	[65]
4	The effect of project approach-based science education program on problem-solving skills of preschool children	[66]

No.	Title	Ref.
5	Enhancing Thai student-teacher problem-solving skills and academic achievement through a blended problem-based learning approach in online flipped classrooms	[67]
6	The effect of an evidence-based practice course on students' lifelong learning skills and problem-solving skills: An educational intervention study	[68]
7	The impact of realistic mathematics education on secondary school students' problem-solving skills: a comparative evaluation study	[69]
8	Using lesson study to help mathematics teachers enhance students' problem-solving skills with teaching through problem solving.	[70]
9	Effectiveness of realistic math education on mathematical problem-solving skills of students with learning disability	[71]
10	Improving problem-solving skills through technology assisted collaborative learning in a first year engineering mathematics course	[72]
11	The factors influencing 21st century skills and problem-solving skills: the acceptance of blackboard as sustainable education	[73]
12	Impact on students' problem-solving skills by making a magnetic safe box	[74]

4. Results and Discussion

Implementation of PjBL in physics learning occurs in two meetings on static fluid material specifically on Archimedes' principle. In the first meeting, the teacher implements three syntaxes of PjBL, namely (i) start with the essential question, (ii) design a plan for the project, and (iii) create a schedule step. In the second meeting, the teacher implements the next three syntaxes of PjBL, namely (iv) monitor the students and the progress of the project, (v) assess the outcome, and (vi) evaluate the experience. The problem that teacher proposed on first meeting is a fishing village and a village with a majority of wood craftsmen, separated by a river that is not too wide and with a flow that is not too fast. The residents of both villages agree to build a bridge to connect the two. They want to build the bridge economically and efficiently while waiting for construction from the government. After studying Archimedes' principle, help the residents to design the bridge. The relationship for implementing the PjBL learning model to increase students' problem-solving skills is shown in Table 3.

Table 3. The relationship of PjBL and problem-solving skills.

PjBL syntax	Students' activities	Problem-solving skills
Start with the essential question	Identifying problems, formulating goals, and gathering facts.	Fact-finding and Problem-finding
Design a plan for the project	Finding ideas and designing steps to be taken.	Idea-finding
Create a schedule	Preparing a schedule of planned activities to be carried out.	Idea-finding
Monitor the students and the progress of the project	Developing solutions, and working on projects.	Solution-finding
Assess the outcome	Making reports on the results of activities to be presented.	Acceptance-finding
Evaluate the experience	Presenting the report that has been made, other students are asked to provide responses	Solution-finding

This research was carried out in two meetings. In the first meeting, teacher start with the essential question, and then teacher with student design a plan for the project and create a schedule. For the first step, the teacher gave a problem and students were asked to identify problems and gather facts. The teacher explained Archimedes' principles and asked the students to formulate goals. In this step, the teacher was trained in fact and problem findings. Then, students were asked to make a group, design a plan for the project, and create a schedule to train students on idea finding. In the second meeting teacher monitors the students' solution-finding and the progress of the project. Students make reports on the results of activities to be presented to train acceptance findings. Last, the teacher evaluates the experience through students' presentations and other students' feedback. This step was to train students to generate solution findings. Table 4 explains the relationship of problem-solving skills indicators in Archimedes' principle material.

Students can carry out project activities that have been designed and compile project result reports, make presentations, and present the results of projects that have been made. The implementation of activities that will be carried out on students' problem-solving skills with the PjBL model is as follows. Figure 3 shows the students' solution findings to answer the teacher's question at the first meeting. This idea was done collaboratively with four to five students in a group. This step is done after students complete fact, problem, and idea finding collaboratively. For acceptance findings, students in groups were asked to present their reports. Table 5 describes the test instruments that use the problem-solving skills indicator.

To find out students' problem-solving achievements regarding Archimedes' principle, the teacher gives a final test with questions as stated in Table 5. The instrument test covered the Osborn Parnes indicators of problem-solving. For the problem-finding indicators, we proposed two questions to ensure the consistency of students' understanding of the problem before moving on to the next step. Table 6 about the summary statistic result of person and item.

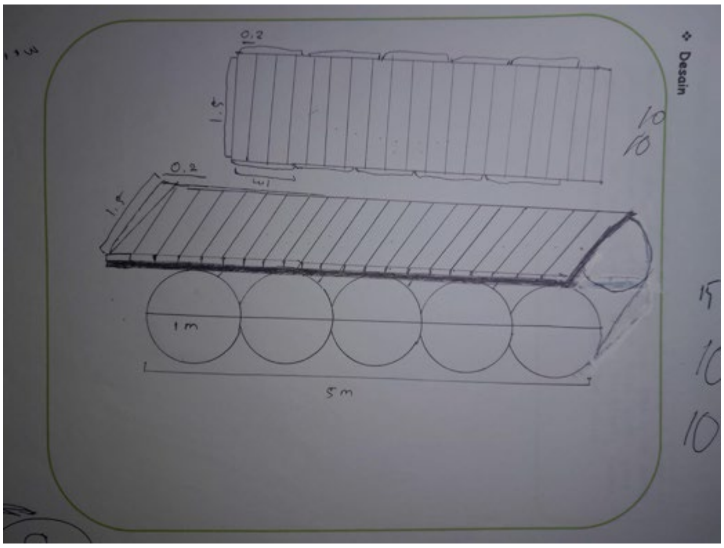

Fig. 3. Design of Pontoon Bridge from student.

Table 4. Problem-solving skills indicators related to Archimedes' Principle.

Indicators	Students' activities on Archimedes' principle
Fact finding	Students do the discovery and establishment of the facts of an issue. The Fact-finding phase ensures student gather enough data to fully understand the problem. At this stage, students find all the known facts and have a relationship with the situation. In this case, the facts about the problems related to Archimedes' principle.
Problem finding	On this phase students allows to dig deeper into the problem and find the root or real problem they want to focus on. Reframe the problem to generate creative and valuable solutions. Students identify a disturbing situation. In this case, students identify problems that arise from problem orientation activities carried out by teachers related to Archimedes' principle.
Idea finding	The student team allows to generate many options for addressing the problem. At this stage, students develop various ideas or concepts for solving problems.
Solution finding	The solution-finding phase allows students to choose the best options from the ideas generated in the idea finding phase. Students can design the project to be implemented, including the activity steps, and analyze the project needs that will be used.
Acceptance finding	This phase is one of the aspects of mathematical creative problem solving (CPS). The indicator of acceptance finding is characterized by students' ability to answer the question by using different methods. The lower acceptance finding is shown by the tendency of the student to use the same methods.

Table 5. Indicators of problem-solving skills in instrument test of Archimedes' Principle.

Problem-solving skills	Question
Fact finding	A child weighs a stone using a spring scale. When weighed in the air, the stone has a gravity of 100 N, but when it is put into a container of water and then weighed, the gravity of the stone becomes 80 N. What event causes this?
Problem finding	A piece of wood floats in a river. If the volume of the submerged wood is 5 m^3 and the density of water is 1000 kg/m^3. What is the upward pressure (buoyancy)?
Problem finding	The weight of a box containing food in the air is 150 N, whereas if the box is weighed in water, its weight will be 100 N. Based on this, what is the density of the object?
Idea finding	Look at the following picture!  Picture of Pasirloa Pandeglang residents crossing the river using a raft due to a collapsed bridge The picture shows that no crossing route can be passed except by crossing the river.

Problem-solving skills	Question
	If this happens to you, and you only find materials such as Drums and planks. Then make a design of the solution that you propose to be able to cross the river easily, referring to the Archimedes principle.
Solution Finding	Based on previous picture, create a design image of the solution you have created! (i) Side view (ii) Top view
Acceptance Finding	Based on the solution finding, analyze the specifications of the equipment used and the amount of materials needed, then analyze them mathematically. Thus, the product you propose can be sure to float! Provide the maximum capacity of the load that can be transported to be able to cross!

Table 6. The summary statistic result of person and item.

	Person Outfit		Item Outfit	
	MNSQ	**ZSTD**	**MNSQ**	**ZSTD**
Mean	1.00	0.05	1.00	-0.29
Standard error	0.04		0.10	
Separation	1.62		4.48	
Reliability	0.72		0.95	

The result as shown in Table 6 indicates the outfit MNSQ value is 1.00 for both, person and item, the implication for measurement is productive to measure because the value is in the range of 0.5 to 1.5. The implication of measurement outfit ZSTD if the value is in the range -1.9 to 1.9 meaning data have reasonable predictability. Both outfit ZSTD calculation results meet this criterion. If a person's reliability < 0.8 it implies that the subject will categorize on two separations, namely high and low. Item reliability is used to verify the item hierarchy. Item separation is 4.48 was implies that the person sample is large enough to confirm the item difficulty hierarchy of the instrument. So that, the item can be separated into high, medium, and low difficulty. This study also found the item reliability is 0.95 which indicates the instrument used has good construct validity. Normality test using Shapiro-Wilk analysis provide result p 0.375 (> 0.05) so the data can assumption of normal. Table 7 about paired sample t-test results.

Table 7. Paired-sample t-test results.

	N	Mean	Std. deviation	SE mean	t	Df	Sig. (2-tailed)
Pre-test	29	9.897	8.625	1.602	13.3	28	0.000
Post-test		50.83	18.85	3.49			

The results of the t-test analysis based on Table 7, carried out showed that there was a significant difference between the students' pretest and post-test results. The average pretest score was 9.897 with a standard deviation of 8.625, while the average posttest score increased sharply to 50.828 with a standard deviation of 18.845. The t-value for the pretest is 13.3, with a significance level of the p-value is 0.000. This shows that there is a very statistically significant difference between the pretest and posttest scores, which indicates that students experienced a significant increase in ability after implementing the PjBL model.

The significant increase in post-test scores shows that the PjBL model is effective in improving students' problem-solving skills on the concept of Archimedes' Principle. The implication is that through PjBL, students not only learn theory but are also faced with real situations that require them to apply theory to solve problems. This approach encourages students to be more active, critical, and creative in thinking, which is reflected in higher post-test results.

The results of the pretest and posttest of problem-solving skills based on the Osborn-Parnes theory are shown in Table 8. There is a difference between the pre-test and post-test scores. The highest increase is in acceptance finding, and the lowest is in solution finding.

Table 8. Pretest and posttest data on students' problem-solving skills.

Problem-solving skills	Pretest	Posttest	Gain (d)
Fact finding	48.28	96.55	48.27
Problem finding	36.78	87.36	50.58
Problem finding	8.97	79.31	70.34
Idea finding	0.57	32.18	31.61
Acceptance finding	0	79.31	79.31
Solution finding	0	13.65	13.65

At the fact-finding indicator, students were able to find all known facts and have a relationship with the situation. This achievement is categorized as high (student's mean score was 96.55). At this stage, the main focus is to collect information related to the problem at hand. This process includes identifying important facts, data, and conditions that affect the problem. By understanding the context in depth, the team can formulate the problem more precisely and prepare the next steps in the problem-solving process. Fact finding ensures that the resulting solution is based on a thorough understanding of the actual situation [75].

At the problem-finding stage, students identified problems that emerged from the problem orientation activities carried out by the teacher related to Archimedes' principle. Two items measure this ability. This posttest achievement is categorized as high (student’s mean score was 83.33). After collecting facts at the fact-finding stage, students analyze the information to find the focus of the problem [76]. This stage opens up opportunities for each student to review the problem from various perspectives. Thus, the problem faced can be defined more precisely and specifically. This plays a very important role in determining the wright solution in the next problem-solving stage.

The value that is not yet optimal is obtained at the idea-finding stage. Students can not develop various ideas or concepts in solving problems. They proposed the same idea, namely the pontoon bridge. This achievement is only categorized as low (the student's mean score was 32.18). At this stage, students are facilitated to produce as many ideas as possible without limiting creativity. Thus, this stage opens up opportunities for students to produce various innovative and appropriate solutions. Students will also sort and ultimately develop ideas that they think are most relevant and appropriate to solve problems [77]. Idea finding helps open up possibilities and ensures that the solution chosen is based on a broad exploration of options. In other words, items are deemed less able to fit the student's abilities. This is because students are not familiar with the scientific reasoning items and they are not taught to answer these kinds of questions in school [78].

In the acceptance finding section, students gained significant improvement. Where students were able to design the project to be implemented, including the steps of the activity, and analyze the needs of the project to be used. This achievement is categorized as high (the student's mean score was 79.31). At this stage, students focus on transforming selected ideas into applicable solutions. At this stage, the team develops a concrete action plan to implement the resulting solution, including identifying potential obstacles and finding ways to overcome them [79].

Low achievement occurs again in the last indicator, namely solution finding. This can be seen that students were unable to carry out the project activities that had been designed to compile project report results, make presentations, and present the results of the projects that had been made. Only 6 people out of 29 students were able to answer this item, as shown in Fig. 4. Thus, the average obtained was not good. This achievement is only categorized as low (student's mean score was only 13.65). This stage is the stage where the ideas that have been generated are evaluated and selected to find the best solution to the problem at hand. This process involves critical analysis of each idea, including assessing its advantages and disadvantages and considering factors such as feasibility, impact, and potential for implementation.

Problem-solving skills are one of the important skills that students must have in learning science, especially in understanding abstract physics concepts such as Archimedes' Principle. By using the PjBL model, students are allowed to explore, experiment, and find their solutions to the problems they face, which not only improves their conceptual understanding but also critical thinking abilities. Figure 4 shows four students who had the minimum extreme score in the pre-test, but they were passed the post-test and successfully involved in the high group.

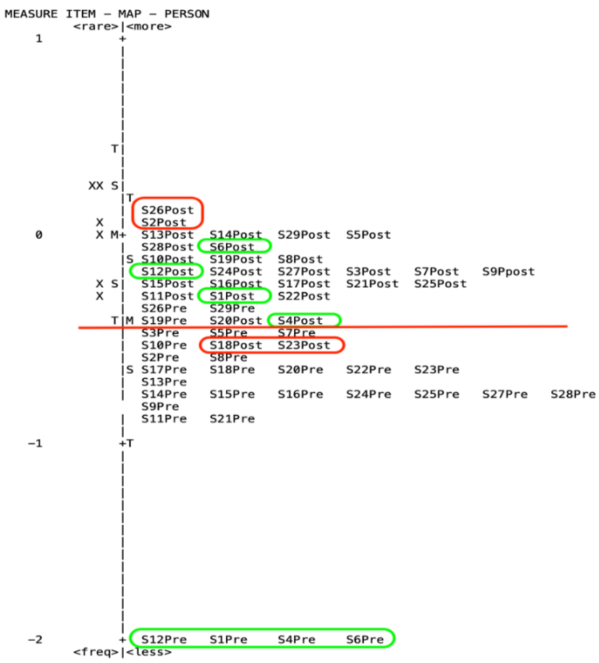

Fig. 4. Item-person wright map.

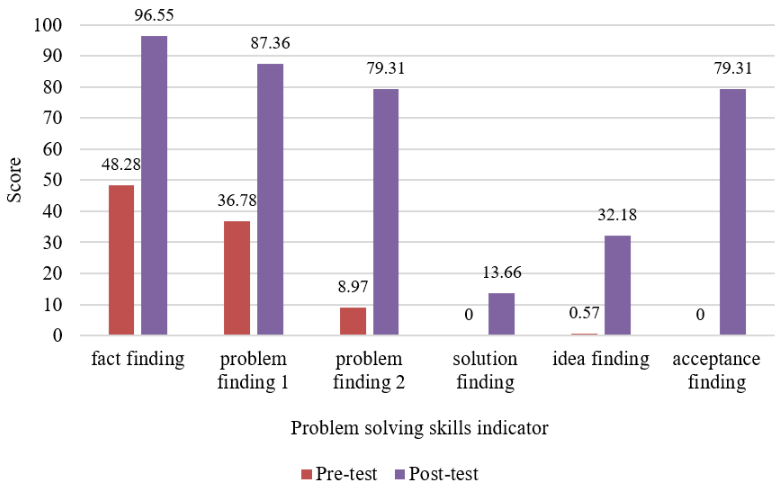

Fig. 5. Pretest and posttest data on students' problem-solving skills.

If viewed on students' average scores, it can be displayed in Fig. 5. Figure 5 it can see the average students' problem-solving before and after taking PjBL, and also visible the improvement. Two indicators of problem-solving skills are still low, namely idea finding and solution finding. The ideas offered are less varied, and this has an impact on the solutions developed which are also still limited. A complete creative problem-solving process requires periods of divergent ideation alternating with convergent evaluation and the ability to judge when each is appropriate [80]. The weakness of this research because it was only carried out in two meetings. It needs to be a concern for teachers for the next learning. Participants may need more time or a different approach to develop creative ideas and choose the right solution.

From Figs. 4 and 5, the PjBL model is effective in improving students' problem-solving skills on the Archimedes Principle concept. The significant increase in student abilities after implementing the PjBL model, as seen in the student's position in Fig. 4, indicates that this approach can help students develop the critical and creative thinking skills needed to solve more complex problems. Therefore, the application of PjBL in physics learning, especially in challenging concepts such as Archimedes' Principle, is highly recommended to improve student learning outcomes.

5. Conclusion

The results of this research are in line with the findings which state that PjBL has a significant positive impact on students' problem-solving abilities. The significant increase from pretest to posttest shows that this learning model is feasible to be applied in teaching physics, especially on topics that require an in-depth understanding of concepts such as Archimedes' Principle. Therefore, physics teachers can consider implementing the PjBL model in their curriculum to improve students' cognitive abilities and problem-solving skills. The research data obtained conclude that there is an increase in problem-solving skills after the intervention or training. In all aspects measured, namely fact finding, problem finding, idea finding, acceptance finding, and solution finding, the posttest score showed a significant increase compared to the pretest score. Although idea-finding and solution-finding aspects showed a lower increase compared to other indicators, there was still a fairly striking improvement from the pretest score. This shows that the intervention carried out succeeded in improving overall problem-solving skills. Despite the increase, idea finding and solution finding still require special attention. It can be considered to add more in-depth training sessions and focus on brainstorming techniques and effective decision-making, to strengthen participants' skills to develop ideas and choose solutions.

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References

1. Glaze, A. (2018). Teaching and learning science in the 21st century: Challenging critical assumptions in post-secondary science. *Education Sciences*, 8(12), 1-8.
2. Cayetano-Jiménez, I. (2024). Bridging the gap: Bioinspired robotics as catalyst for interdisciplinary education. *Frontiers in Education*, 9, 1-14.
3. Yew, E. and Goh, K. (2016). Problem-based learning: An overview of its process and impact on learning. *Health Professions Education*, 2(2), 75-79.
4. Buckley, J.; Seery, N.; and Canty, D. (2018). Investigating the use of spatial reasoning strategies in geometric problem solving. *International Journal of Technology and Design Education*, 29(2), 341-362.
5. Arici-Ozcan, N.; Cekici, F.; and Arslan, R. (2019). The relationship between resilience and distress tolerance in college students: The mediator role of cognitive flexibility and difficulties in emotion regulation. *International Journal of Educational Methodology*, 5(4), 525-533.
6. Ramey, K.E.; Stevens, R.; and Uttal, D.H. (2020). In-FUSE-ing STEAM learning with spatial reasoning: Distributed spatial sensemaking in school-based making activities. *Journal of Educational Psychology*, 112(3), 466.
7. Suryaningsih, T. (2019). Hard work and problem solving based on krulik-rudnick's heuristic theory on project based learning with oqale approach of 5th grade elementary school students. *JMIE (Journal of Madrasah Ibtidaiyah Education)*, 3(1), 91.
8. Shamdas, G. (2023). Problem-solving skills for middle school students through the STEM-based PBL model. *Symposium of Biology Education (Symbion)*, 3, 75.
9. Narmaditya, B.; Wulandari, D.; and Sakarji, S. (2018). Does problem-based learning improve critical thinking skill?. *Jurnal Cakrawala Pendidikan*, 37(3), 378-388.
10. Putri, M.A.N.; and Dwikoranto, D. (2022). Implementation of STEM integrated project based learning (PjBL) to improve problem solving skills. *Berkala Ilmiah Pendidikan Fisika*, 10(1), 97-106.
11. MacLeod, M.; and Van der Veen, J.T. (2020). Scaffolding interdisciplinary project-based learning: A case study. *European Journal of Engineering Education*, 45(3), 363-377.
12. Nuraini, N.; Asri, I.H.; and Fajri, N. (2023). Development of project based learning with STEAM approach model integrated science literacy in

improving student learning outcomes. *Jurnal Penelitian Pendidikan IPA*, 9(4), 1632-1640.

13. Safaruddin, S.; Ibrahim, N.; Juhaeni, J.; Harmilawati, H.; and Qadrianti, L. (2020). The effect of project-based learning assisted by electronic media on learning motivation and science process skills. *Journal of Innovation in Educational and Cultural Research*, 1(1), 22-29.
14. Almulla, M.A. (2020). The effectiveness of the project-based learning (PBL) approach as a way to engage students in learning. *Sage Open*, 10(3), 1-15.
15. Kiong, T.T.; Rusly, N.S.M.; Abd Hamid, R.I.; Swaran, S.C.K.; and Hanapi, Z. (2022). Inventive problem-solving in project-based learning on design and technology: A needs analysis for module development. *Asian Journal of University Education*, 18(1), 271-278.
16. Santyasa, I.W.; Rapi, N.K.; and Sara, I. (2020). Project based learning and academic procrastination of students in learning physics. *International Journal of Instruction*, 13(1), 489-508.
17. Uden, L.; Sulaiman, F.; Ching, G.S.; and Rosales Jr, J.J. (2023). Integrated science, technology, engineering, and mathematics project-based learning for physics learning from neuroscience perspectives. *Frontiers in Psychology*, 14, 1-15.
18. Lou, S.J.; Chou, Y.C.; Shih, R.C.; and Chung, C.C. (2017). A study of creativity in CaC2 steamship-derived STEM project-based learning. *Eurasia Journal of Mathematics, Science and Technology Education*, 13(6), 2387-2404.
19. Setiawan, A.; and Bharati, D.A.L. (2018). Developing HOT project-based-speaking assessment to stimulate the students' critical thinking and creativity. *English Education Journal*, 8(3), 301-307.
20. Siew, N.M.; and Ambo, N. (2018). Development and evaluation of an integrated project-based and STEM teaching and learning module on enhancing scientific creativity among fifth graders. *Journal of Baltic Science Education*, 17(6), 1017-1033.
21. Sumarni, W.; and Kadarwati, S. (2020). Ethno-STEM project-based learning: Its impact to critical and creative thinking skills. *Jurnal Pendidikan IPA Indonesia*, 9(1), 11-21.
22. Wahyudi, W.; and Winanto, A. (2018). Development of project based blended learning (PjB2L) model to increase pre-service primary teacher creativity. *Jurnal Pendidikan dan Pengajaran*, 51(2), 93-109.
23. Firmansyah, J.; Suhandi, A.; Setiawan, A.; and Permanasari, A. (2022). PJB-Lab: Practicing 4C skills in physics practicum. *Physics Education*, 57(3), 1-8.
24. Martawijaya, M.A.; Rahmadhanningsih, S.; Swandi, A.; Hasyim, M.; and Sujiono, E.H. (2023). The effect of applying the Ethno-STEM-Project-based learning model on students' higher-order thinking skill and misconception of physics topics related to Lake Tempe, Indonesia. *Jurnal Pendidikan IPA Indonesia*, 12(1), 1-13.
25. Hartini, S.; Liliasari, L.; and Sinaga, P. (2023). Students' problem solving skill in nuclear physics course through NPIRL. *Momentum: Physics Education Journal*, 7(2), 279-289.

26. Nuhoglu, H.; and Akgül, S. (2019). Analysis of the relation between creativity level and problem solving skills of gifted and talented students. *Educational Research and Reviews*, 14(15), 518-532.
27. Widya, W.; Nurpatri, Y.; Indrawati, E.S.; and Ikhwan, K. (2020). Development and application of creative problem solving in mathematics and science: A literature review. *Indonesian Journal of Science and Mathematics Education*, 3(1), 106-116.
28. Arsyad, Z.; Wati, M.; and Suyidno, S. (2020). The effectiveness of the module static fluid with authentic learning to train students problem-solving skills. *SEJ (Science Education Journal)*, 4 (2), 113–128.
29. Saefullah, A.; Suherman, A.; Utami, R.T.; Antarnusa, G.; Rostikawati, D.A.; and Zidny, R. (2021). Implementation of PjBL-STEM to Improve students' creative thinking skills on static fluid topic. *JIPF (Jurnal Ilmu Pendidikan Fisika)*, 6(2), 149-157.
30. Wati, M.; Misbah, M.; Haryandi, S.; and Dewantara, D. (2020). The effectiveness of local wisdom-based static fluid modules in the wetlands environment. *Momentum: Physics Education Journal*, 42, 102-108.
31. Mohazzab, P. (2017). Archimedes' principle revisited. *Journal of Applied Mathematics and Physics*, 5(4), 836-843.
32. Watanabe, E.; and Utsunomiya, T. (2003). Analysis and design of floating bridges. *Progress in Structural Engineering and Materials*, 5(3), 127-144.
33. Khoiri, N.; Ristanto, S.; and Kurniawan, A.F. (2023). Project-based learning via traditional game in physics learning: Its impact on critical thinking, creative thinking, and collaborative skills. *Jurnal Pendidikan IPA Indonesia*, 12(2), 286-292.
34. Suradika, A.; Dewi, H.I.; and Nasution, M.I. (2023). Project-based learning and problem-based learning models in critical and creative students. *Jurnal Pendidikan IPA Indonesia*, 12(1), 153-167.
35. Hikmah, N.; Febriya, D.; Asrizal, A.; and Mufit, F. (2023). The impact of the project-based learning model on students' critical and creative thinking skills in science and physics learning: A meta-analysis. *Jurnal Penelitian Pendidikan IPA*, 9(10), 892-902.
36. Marnewick, C. (2023). Student experiences of project-based learning in agile project management education. *Project Leadership and Society*, 4, 1-10.
37. Azmi, N.; and Festiyed, F. (2023). Development of physics learning assessment instrument in project-based learning model to improve 4C skills. *Jurnal Penelitian Pendidikan IPA*, 9(4), 1798-1804.
38. Prajoko, S.; Sukmawati, I.; Maris, A.F.; and Wulanjani, A.N. (2023). Project based learning (PjBL) model with STEM approach on students' conceptual understanding and creativity. *Jurnal Pendidikan IPA Indonesia*, 12(3), 401-409.
39. Rosidin, U.; and Herliani, D. (2023). Development of assessment instruments in project-based learning to measure students scientific literacy and creative thinking skills on work and energy materials. *Jurnal Penelitian Pendidikan IPA*, 9(6), 4484-4494.
40. Akben, N. (2020). Effects of the problem-posing approach on students' problem solving skills and metacognitive awareness in science education. *Research in Science Education*, 50(3), 1143-1165.

41. Munir, M.J.M.; Wati, M.; and Mahtari, S. (2024). Materi ajar gerak lurus berbasis authentic learning menggunakan model collaborative problem solving: Validitas aspek. *Journal of Authentic Research*, 3(1), 10-24.
42. Wati, M.; Lestari, D.M.; and Mahtari, S. (2024). The effect of digital worksheets on dynamic fluids with authentic learning in training problem-solving skills. *Jurnal Ilmiah Pendidikan Fisika*, 8(2), 266-275.
43. Andini, A.D.; and Mahardika, I.K. (2024). Creative problem solving accompanied by wordwall as an assessment media: Does it have an impact on students' higher level physics thinking abilities? *International Journal of Education and Teaching Zone*, 3(2), 152-160.
44. Isaksen, S.G. (2023). Developing creative potential: The power of process, people, and place. *Journal of Advanced Academics*, 34(2), 111-144.
45. Fiandini, M.; Nandiyanto, A.B.D.; Al Husaeni, D.F.; Al Husaeni, D.N.; and Mushiban, M. (2024). How to calculate statistics for significant difference test using SPSS: Understanding students comprehension on the concept of steam engines as power plant. *Indonesian Journal of Science and Technology*, 9(1), 45-108.
46. Landaverde-Alvarado, C.J. (2024). Problem-based learning (PBL) and project-based learning (PjBL) in a continuously improving chemical engineering laboratory experience. *Chemical Engineering Education*, 58(2), 120-130.
47. Wibowo, A.M.; Utaya, S.; Wahjoedi, W.; Zubaidah, S.; Amin, S.; and Prasad, R.R. (2024). Critical thinking and collaboration skills on environmental awareness in project-based science learning. *Jurnal Pendidikan IPA Indonesia*, 13(1), 103-115.
48. Cioc, C.; Haughton, N.; Cioc, S.; and Napp, J. (2022). A Model for incorporating information literacy and collaboration in a project-based learning pedagogical exercise with application to a fluid mechanics course. *International Journal of Mechanical Engineering Education*, 50(4), 955-977.
49. Septiadevana, R.; and Abdullah, N. (2024). Developing STEM project-based learning module for primary school teachers: A need analysis. *International Journal of Evaluation and Research in Education (IJERE),* 13(4), 2585-2593.
50. Husna, M.; and Rintayati, P. (2024). The influence of project-based learning and problem-based learning models on science learning ability from the perspectives of learning interest: Project based learning and problem based learning. *Multidisciplinary Science Journal*, 6(8), 1-10.
51. Rijken, P.E.; and Fraser, B.J. (2023). Effectiveness of project-based mathematics in first-year high school in terms of learning environment and student outcomes. *Learning Environments Research*, 27, 1-23.
52. Sulaiman, F.; Rosales JR, J.J.; and Kyung, L.J. (2024). The effectiveness of integrated science, technology, engineering and mathematics project-based learning module. *International Journal of Evaluation and Research in Education (IJERE),* 13 (3), 1740-1754.
53. Taylor, J.C.; Allen, L.M.; Van, J.; and Moohr, M. (2024). The effects of project-based learning on student behavior and teacher burnout in an emotional/behavioral support classroom. *Journal of Emotional and Behavioral Disorders*, 32(2), 81 - 94.

54. Li, M.M.; and Tu, C.C. (2024). Developing a project-based learning course model combined with the think–pair–share strategy to enhance creative thinking skills in education students. *Education Sciences*, 14(3), 233.
55. Köpeczi-Bócz, T. (2024). The impact of a combination of flipped classroom and project-based learning on the learning motivation of university students. *Education Sciences*, 14(3), 240.
56. Wagiran, W.; Mujiyono, M.; Setiadi, B.R.; Wibowo, Y.E.; Surahmanto, F.; Agata, D.A.; and Areeprasert, C. (2023). Temperature distribution in bio stove using saw dust: An integrated project-based learning. *Indonesian Journal of Science and Technology*, 8(1), 127-140
57. Wahyudi, W.; Setiawan, A.; Suhandi, A.; and Samsudin, A. (2024). Technology-supported project-based learning: Trends, review and future research in science, technology and engineering education. *ASEAN Journal of Science and Engineering*, 4(1), 119-126.
58. Purwianingsih, W.; Lestari, D.A.; and Rahman, T. (2023). Profile of communication skills of students in groups with the application of blended learning using project-based learning model. *Indonesian Journal of Multidiciplinary Research*, 3(1), 159-168.
59. Nurani, A.S.; Mahmudatussa'adah, A.; Karpin, K.; Juwaedah, A.; Setiawati, T.; and Muktiarni, M. (2024). Interactive multimedia design of motion graphics using a project-based learning approach for vocational education students: Experiments in cooking taliwang chicken. *ASEAN Journal of Science and Engineering Education*, 4(2), 163-174.
60. Putra, R.D.; and Sakti, A.W. (2022). Student development: Implementation of water rocket media as a project-based learning tool to improve the literacy of junior high school students during the pandemic. *ASEAN Journal for Science Education*, 1(1), 1-8.
61. Fatmala, T.R.; Windayani, N.; and Irwansyah, F.S. (2023). Application of project-based worksheets for making conditioner from aloe vera (Aloe vera L.) to develop students' scientific performance. *ASEAN Journal for Science and Engineering in Materials*, 2(2), 159-168.
62. Darojah, T.Z.; Windayani, N.; and Irwansyah, F.S. (2024). Implementing project-based worksheets on making kaolin soap with the addition of kefir curd to develop students' scientific performance in Islamic school. *ASEAN Journal for Science and Engineering in Materials*, 3(1), 59-74.
63. Arianto, F.; and Hanif, M. (2024). Evaluating metacognitive strategies and self-regulated learning to predict primary school students' self-efficacy and problem-solving skills in science learning. *Journal of Pedagogical Research*, 8(3), 301-319.
64. Sa-ngiemjit, M.; Vázquez-Alonso, Á.; and Mas, M.A.M. (2024). Problem-solving skills of high school students in chemistry. *International Journal of Evaluation and Research in Education (IJERE)*, 13(3), 1825-1831.
65. Benjamin, A. (2024). Studying the student's perceptions of engagement and problem-solving skills for academic achievement in chemistry at the higher secondary level. *Education and Information Technologies*, 29(7), 8347-8368.

66. Güley, B.; and Keskinkılıç, A. (2024). The effect of project approach-based science education program on problem-solving skills of preschool children. *Humanities and Social Sciences Communications*, 11(1), 1-10.
67. Pimdee, P.; Sukkamart, A.; Nantha, C.; Kantathanawat, T.; and Leekitchwatana, P. (2024). Enhancing Thai student-teacher problem-solving skills and academic achievement through a blended problem-based learning approach in online flipped classrooms. *Heliyon*, 10(7), 1-19.
68. Jalinus, N.; Syahril, S.; and Nabawi, R.A. (2019). A comparison of the problem-solving skills of students in PjBL versus CPjBL model: An experimental study. *Journal of Technical Education and Training*, 11(1), 36-4
69. Yılmaz, E.; and Griffiths, M.D. (2023). Children's social problem-solving skills in playing videogames and traditional games: A systematic review. *Education and Information Technologies*, 28(9), 11679-11712.
70. Roorda, G.; de Vries, S.; and Smale-Jacobse, A.E. (2024). Using lesson study to help mathematics teachers enhance students' problem-solving skills with teaching through problem solving. *Frontiers in Education*, 9, 1-17.
71. Şanal, S.Ö.; and Elmali, F. (2024). Effectiveness of realistic math education on mathematical problem-solving skills of students with learning disability. *European Journal of Special Needs Education*, 39(1), 109-126.
72. Anitha, D.; and Kavitha, D. (2022). Improving problem-solving skills through technology assisted collaborative learning in a first year engineering mathematics course. *Interactive Technology and Smart Education*, 20(4), 534-553.
73. Alturki, U.; and Aldraiweesh, A. (2023). The factors influencing 21st century skills and problem-solving skills: The acceptance of blackboard as sustainable education. *Sustainability*, 15(17), 1-22.
74. Pazmino, A.; Mosquera, J.; Roblero, J.; Romero-Vera, A.; and Gutiérrez, E.D. (2023). Impact on students' problem-solving skills by making a magnetic safe box. *Physics Education*, 58(5), 055016.
75. van Hooijdonk, M.; Mainhard, T.; Kroesbergen, E.H.; and van Tartwijk, J. (2020). Creative problem solving in primary education: Exploring the role of fact finding, problem finding, and solution finding across tasks. *Thinking Skills and Creativity*, 37, 100665.
76. Rahman, M.M. (2019). 21st century skill'problem solving': Defining the concept. *Asian Journal of Interdisciplinary Research*, 2(1), 64-74.
77. Kim, J.Y.; Choi, D.S.; Sung, C.S.; and Park, J.Y. (2018). The role of problem solving ability on innovative behavior and opportunity recognition in university students. *Journal of Open Innovation: Technology, Market, and Complexity*, 4(1), 1-13.
78. Wati, M.; Mahtari, S.; Hartini, S.; and Amelia, H. (2019). A Rasch model analysis on Junior High School students' scientific reasoning ability. *International Journal of Interactive Mobile Technologies*, 13 (7), 141-149.
79. Yayuk, E.; and As' ari, A.R. (2020). Primary school students' creative thinking skills in mathematics problem solving. *European Journal of Educational Research*, 9(3), 1281-1295.
80. Graesser, A.C.; Fiore, S.M.; Greiff, S.; Andrews-Todd, J.; Foltz, P.W.; and Hesse, F.W. (2018). Advancing the science of collaborative problem solving. *Psychological Science in The Public Interest*, 19(2), 59-92.