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The Effect of Problem Based Learning Model on Creative and Critical Thinking Skills in Static Fluid Topics

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Abstract. Creative and critical thinking skills are one of the demands of new skills needed by students in the current era. One of the learning models that can sharpen creative and critical thinking skills is Problem based learning (PBL). Heretofore, research related to creative and critical thinking skills with PBL in understanding static fluid material is still minimal. Therefore, this research explored it. This study aimed to analyze the effect of PBL on students' creative and critical thinking skills. This type of research is experimental with a total of 58 students, both experimental class and control class in 10^{th}-grade science class Christian Senior High School YPKPM Ambon. The research procedure in the form of creative and critical thinking skills tests carried out during the research process and data analysis used was the independent sample t-test. The results showed that the average value of the experimental class students' learning achievement related to students' creative and critical thinking skills was higher than the conventional class. This implies that PBL facilitates in improving students' creative and critical thinking skills on static fluid.
Keywords: PBL, creative, critical, static fluid

Introduction

Physics is one of the sciences that makes a significant contribution to the needs of society in the field of science and technology. It supports society to survive, develop, and evolve to meet global challenges. Therefore, experts, researchers, and teachers, together with the government, make regulations so that academic units can innovate in learning to prepare students' quality to live and work (Serdyukov, 2017). One of the skills that need to be prepared is the ability of physics. Various recent studies have underlined the importance of physics in improving scientific and technological competence (Bigozzi et al., 2014). Technological advances in the form of hardware and software have been introduced to students in the classroom to assist in building their own knowledge and ideas to be presented in front of the class. As an important report, the results of the PISA assessment show clearly that the use of technology in education can improve students' social skills in the form of writing skills, designing media, creating digital library galleries, researching, and communication. The effect on students is the ability to learn more quickly and exclusively (Smeda et al., 2014). A study on medical students in the USA reported that students fail to master the concept based on the assessment. It means that the assessment serves as a diagnostic tool to develop individuals to overcome deficiencies. Therefore, students who fail in learning take the retest, starting with independent learning and following additional programs from the teacher to take the retest until they achieve 90% mastery (Lipsky et al., 2019). Students who have academic achievements are a concern for the world of education, which is a benchmark for success in work. Accordingly, the learning process carried out must be supported by professional teachers who can master and apply the skills taught in the process (Bakar, 2018). The effectiveness of learning is influenced by the characteristics of teachers and students (Sung et al., 2016), learning materials (Batlolona et al., 2019), IT mastery (Panyajamorn et al., 2018), as well as other aspects related to the learning situation.

Constructivist experts have offered various effective solutions that provide stimulation for students to develop their knowledge and the complexity of building basic knowledge to be more active in learning (Niederriter et al., 2020). A student-centred paradigm shift is an effort to promote students to be independent, be active, build scientific ideas, explore, cooperate, build investigations, and participate in various scientific projects (Bechter et al., 2019). Teachers are expected to create learning environment conditions that can provide comfort to students, encourage students to learn, and provide opportunities to play an active role in constructing the concepts they learn (Tanner, 2013). Good learning conditions in collaboration with peers will enhance students' professional development. This is proved by the collaboration of fellow medical students in the Netherlands (Jansen et al., 2019).

The results of studies in America inform that the problem-solving ability of adults is of particular concern, in which only 31% of adults showed the ability to solve problems. Consequently, it is crucial to learn how to solve problems and the factors that influence them. (Xiao et al., 2019) so a particular application is crucial to train students' critical thinking (Utriainen et al., 2017) and creative ones who can prepare productive generations who can take the initiative in a decision (Utriainen et al., 2017). Creative and critical thinking skills have different constructions because they are the result of human behaviour. In general, creative thinking is correlated with critical thinking and problem solving (Yazar, 2015). Critical and creative are embryos that can evolve into innovation. Today's students need to be equipped with creative skills in order to produce solutions to enrich ideas and styles to produce quality products (Avvisati et al., 2014).

Physics is considered one of the science products that are still abstract and requires a series of scientific processes to obtain a concept (Pincelli et al., 2020). This indicates that physics is a valuable tool to identify and represent students' mentality in physics (Leone & Rinaudo, 2020). Physics learning is built through several learning processes to involve students in developing knowledge during the tasks they are faced with (Ramma et al., 2018). Physics is directed to find out something and act so that it can help students to gain a deeper understanding of the natural environment and use mathematics as a bridge to solve physics problems meditation. This is because people who are good at physics must be proficient in mathematics. Sometimes people who have deficiencies in mathematics will face an obstacle in solving physics problems (De Luca et al., 2020). This is evidenced by the very low results of the seventh grade students' responses to physics learning (Tsivitanidou et al., 2011); (Tasker & Herrenkohl, 2016).

PBL is a learning model that is recommended in this study to solve authentic problems through scientific stages. Students can learn knowledge related to the physics problem-solving process and have the skills and produce a generation that is proficient in science and technology (Günter & Alpat, 2017). In England, students in vocational schools are well equipped with skills. It begins with a given case, and students provide solutions to solve the problem. Therefore, when you graduate from school and look for work in the industrial world, you are ready and mature in your work (Peters, 2015). Moreover, veterinary students in Myanmar, France, Senegal, Vietnam, and Cameroon solve problems through PBL (Eveillard et al., 2017). Another case is in Japan, where PBL solves problems in the operating room (Komasawa et al., 2018). In addition, undergraduate physics students at the Faculty of Engineering in Bilbao (University of the Basque Country) must solve physics problems. In introductory physics course 1, the materials that must be mastered are electromagnetics and wave. Then, mechanics and thermodynamics must be mastered in physics 2. Mastery of this material is support in solving everyday physics problems (Macho & Elejalde, 2013). This situation shows that PBL is very encouraging in increasing students' understanding of what they are learning to improve learning outcomes. As shown in a study in Turkey, where PBL assisted by Augmented Reality (AR) can improve academic abilities and foster positive attitudes towards learning physics (Fidan & Tuncel, 2019).

In 1969, there were 20 medical students at McMaster University, Hamilton, Ontario. Students are involved in PBL in biomedical problems and clinical problems in collaboration with peers and guided by a tutor. PBL can be applied if supported by a constructivist learning environment (Schmidt et al., 2009). Medical schools in Australia adopted PBL as an effective learning method for them (Sanson-Fisher & Lynagh, 2005), Europe and Asia adopted PBL to be developed in the learning curriculum (Tiwari et al., 2006), besides that PBL was adopted in science, economics and business (Stanley & Marsden, 2012), Engineering (Dahlgren & Dahlgren, 2002), Agriculture (Abbey et al., 2017), Psychology (Dunsmuir et al., 2017), Sports (Young et al., 2018), and Biology (Tatner & Tierney, 2016). PBL recommends a constructivist-based humanist learning environment that includes cognitive flexibility (Deubel, 2003). PBL cases can stimulate students to learn to identify the root of the problem or the primary source of problems that impact the emergence of other problems. This learning activity can help students to improve their critical thinking skills and develop innovation skills. Cognitive flexibility represents the subject matter to understand the complexities of the knowledge domain (Yu et al., 2019). Cognitive flexibility can be increased by providing opportunities for students to provide ideas that describe their understanding of the problem (Lin et al., 2014). Cognitive flexibility can foster divergent thinking creativity in presenting problems (Ritter et al., 2020). This study aimed to analyze the effect of PBL on creative and critical thinking skills in static fluid learning. With the development of existing questions, it is hoped that students can think creatively and critically in analyzing and solving physics problems that are considered complicated so that they are expected to become competent and professional candidates for physics scientists.

Method

The research applied was true experimental with posttest only control group design. The tenth grade had five classes consisting of Class A, B, C, D, E. Each class had the same opportunity to become a research class. Class A and B had homogeneous abilities. These classes were superior and could be categorized as intelligent and prepared by the school to participate in national or international science olympiads. To improve students' scientific abilities, the school had collaborated with universities and related institutions to train in solving science problems and producing scientific products. Classes C and D had characteristics with different abilities in which students with high, medium and low ability predicates. This ability had been mapped by the school since the admission selection for new students from junior high school to high school level. In class E, the characteristics of students' abilities were still low. Accordingly, the research was directed at classes C, and D. The determination of the experimental class (EC) and control class (CC) was determined randomly or by lottery. Class C used the PBL learning model, and class D used conventional learning. Each class learned the same topic that was static fluid.

The population of this study was the 10th-grade science students of Christian Senior High School YPKPM Ambon, with a total of 58 students. The experimental class consisted of 30 students, and the control class was as many as 28 students. Before this research was carried out, instrument validation had been carried out on two experts in their fields. One has theoretical physics expertise, and the other is a physics learning expert. The instrument was tested on five high schools in Ambon City and Central Maluku Regency, including Public Senior High School 1 Ambon, Public Senior High School 4 Ambon, Public Senior High School 5 Ambon, Public Senior High School 14 Central Maluku, and Public Senior High School 57 Central Maluku. The selection of the location for the instrument trial was due to the collaboration through the teacher professional education program that fosters graduates to become professional teachers. The teacher professional education program was in lecture activities carried out for one year for pre-service classes. This activity was marked by 6 months of learning activities on campus and 4 months of internships at partner schools. These schools had collaborated to carry out the practical process of field experiences in learning and other school activities. The last 2 months were used for preparation for performance exams and final exams. Therefore, to facilitate research activities, it was carried out in these schools. The number of samples tested was 250 students who had learned the concept of static fluid, namely eleventh and twelfth graders.

Data collection instruments consisted of treatment instruments and measurement instruments. The treatment instrument was an observation sheet on implementing learning with the PBL model for six meetings. The measurement instrument in the form of final test questions for creative skills as many as 10 were developed (Torrance, 2006) consisting of Fluency, Flexibility, Originality and Elaboration, which have criteria that can be shown in Table 1. Critical skills test developed as many as 10 questions adapted from the rubric (Facione & Facione, 1994) using 0, 1, 2, 3, 4. The range of scores for critical thinking skills was adapted from the Ministry of Education of Malaysia, shown in Table 2. The purpose of the final test was to re-confirm the concepts that had been learned during the learning process. The test instruments developed both processes and explored more static fluid physics concepts related to contextual conditions or local wisdom in Maluku Province. The other instrument was an interview sheet in the form of questions that had been prepared to re-check students' understanding related to the concepts that had been studied. In addition, the interview instrument with students was related to the PBL model used. The documentation was in the form of the learning process, the results of student answers, and conducting interviews.

Table 1. Creative Thinking Skills Score Based on Indicator

Creative Indicators	Score	Description
Fluency	0	Students cannot provide answers/ideas scientifically
	2	Students can give one or two answers scientifically
	4	Students can give three or more answers scientifically
Flexibility	0	Students cannot provide ideas/methods scientifically
	2	Students can give one or two ideas/methods scientifically
	4	Students can provide three scientific ideas/methods
Originality	0	Students cannot provide answers / ideas are general / do not have scientific authenticity
	2	Students can provide unique/latest scientific ideas
	4	Students can provide very unique/very scientifically up-to-date ideas
Elaboration	0	Students cannot provide additional scientific answers/ideas
	2	Students can provide additional scientifically simple answers/ideas
	4	Students can provide answers / ideas scientifically

Table 2. Critical Thinking Skills Score Range

Score range	Critical thinking skill level
80-100	Very critical
60-79	Critical
40-59	Quite Critical
20-39	Less Critical
0-19	Not Critical

The data collection procedure was started by conducting a pretest for static fluid material to measure students' creative and critical abilities. After this process was carried out, it was seen that students' creativity and criticality were still low, so they were treated using the PBL learning model. At each meeting, student worksheets in the form of cases were given according to the material to be studied to explore and measure students' creative and critical skills. The following process was the posttest process for students.

Data analysis was an activity that was carried out after data from data sources were collected. Hypothesis testing in this study consisted of three types, namely hypothesis testing on learning outcomes, creative thinking skills, and critical thinking. Hypothesis testing on these three dependent variables can only be determined after the prerequisite test was carried out. This prerequisite test was conducted to determine whether the data were normally distributed or not so that the statistical technique to be used could be determined. If the data were normally distributed, the parametric statistical technique was used for hypothesis testing, namely the T-test. If the data was not normally distributed, the non-parametric statistical technique must be used, namely the Mann-Whitney U test. Therefore, before testing the hypothesis, a prerequisite test was first carried out. Data analysis used SPSS 16.0 software for windows.

Result and Discussion

Data on students' academic abilities were obtained after going through a series of learning processes after using the PBL model. The description of students' academic abilities was shown in Table 3.

Table 3. The Description of Student Academic Ability

Classes	The Highest Score	The Lowest Score	The Average Value	Standard Deviation
EC	88	60	74,40	8,34
CC	88	56	73,29	7,24

Table 3 shows that the average value of the experimental class is 73.29, and the control class is 74.40. This shows that the average value of the PBL class is higher than the conventional class because the PBL stages facilitated students' creative and critical thinking. Students were led directly in authentic learning. Students were trained to identify physical problems given, search, investigate systematically, critically, and logically to find themselves with existing knowledge and answers to problems in learning to produce original, traceable comprehensive answers. This is in line with Dawilai et al. (2019), which states that PBL can motivate students to be more active, flexible and encourage the formation of study groups in solving problems given to stimulate students to think critically and creatively in producing good work. In addition, teachers can also teach students to collaborate with peers in the construction of scientific thinking in a more positive direction to encourage the improvement of academic abilities. PBL also regulates students to think more systematically and regulates self-discipline. PBL that was used during research that was oriented to everyday phenomena is one of the ways that teachers do in inculcating good concepts.

PBL can help students explore the causes of problems, formulate real problems, and offer solutions to those problems. It encourages students to boldly work together in cooperative groups to solve concrete problems with their respective group members and present ideas in front of the class and argue to defend their opinions in front of many people (Kardoyo et al., 2020). In PBL, generally, unstructured problem cases are reserved for teachers. Students define problems, collect data, and conduct group discussions to analyze data and produce solutions in collaborative work (Pease & Kuhn, 2011). Therefore, PBL is meta-cognitive active participation, motivation, the behavior of students for their learning process. Thus, PBL learners set their own goals, actively control the learning process by planning activities, organizing content, and following the independent learning process. PBL also provides a theoretical framework in evaluating the learning process (Amira et al., 2019).

The experimental and control classes can be reviewed based on the number of samples of the two classes to determine the t-test and seen based on the homogeneity of the data. The results of the EC and CC academic ability hypothesis testing can be shown in Table 4.

Table 4. The Hypothesis Test Results of Students' Academic Ability

Classes	$\bar{x}$	N	T_{count}	T_{table}	Asymp-Sig
EC CC	73,29 74,40	30 28	0,514	1,670	0,610

The data in Table 4 provides information that the Asymp-Sig value is 0.610 > 0.05. This means that there is no difference between the academic abilities of students in the two classes. Based on the value of t_{count} 0,514 and t_{table} is 1,670. It means that $t_{count} < t_{table}$, so the initial hypothesis H_o is accepted, and it can be concluded that EC's academic ability is less than or equal to CC even though it has been given different treatment.

Learning using PBL is more effectively used to improve students' creative and critical thinking skills when compared to conventional learning on static fluid material in Science 10th-grade class at Christian Senior High School YPKPM Ambon. The differences in students' creative and critical thinking skills in the two classes were caused by the different learning treatments in the two classes. In the experimental class, the students were taught using the PBL model by involving students' thinking processes and were given the opportunity to identify problems following the facts and physics cases in the form of hydrostatic pressure, Pascal's law, and Archimedes' law. Therefore, students could train their attention to focus on identifying problems regarding cases in the static fluid. It increased creative and critical thinking skills. This is following the research of Estrada., et al. (2018) which states that in particular, problem-based learning (PBL) methods provide opportunities for students to be part of an external learning experience, thereby promoting active learning, using the environment as a learning resource, and having fun for students. In addition, PBL helps develop students' knowledge in a more flexible convergent and divergent manner (Woolfolk, 2016). In addition, the learning carried out based on the student worksheet (LKPD) followed the PBL syntax. It is oriented towards questions and problems that train creative thinking skills so that students are more focused on determining the problems sought through experiments and understanding physics concepts through actual experiments. If professional teachers apply PBL learning, it is suspected that the three dependent variables, namely the value of learning achievement, critical thinking skills, and creative students taught by PBL, will be higher than the scores of students with conventional learning (Foo et al., 2021).

Data on students' creative thinking skills is the value obtained from the test results after using the PBL model. This test related to the concept of static fluid was given at the final meeting. Descriptions of high and low scores on students' creative thinking skills can be seen in Table 5.

Table 5. Description of the Value of Creative Thinking Skills

Classes	The Highest Score	The Lowest Score	The Average Score	Standard Deviation
Experiment	4	2	3	.83
Control	2	1	1	.50

Table 5 provides information that the average values between EC and CC are very different, namely, 0.83 and 0.50. Furthermore, the initial ability data of students in EC and CC were tested for normality and homogeneity as a prerequisite for hypothesis testing. The analysis prerequisite tests showed that the distribution of EC and CC data in the form of posttest creative thinking skills was not normally distributed. Therefore, the next step was to test the hypothesis by using a nonparametric test. The chosen nonparametric test was the one-sided U or Mann-Whitney test. Based on the data collected, the U test was suitable for data in the form of scores. The results of the hypothesis test of creative thinking skills in both classes can be seen in Table 6.

Table 6. Creative Thinking Skills Hypothesis Test Results

Classes	$\bar{x}$	N	Z_{count}	Z_{table}	Asymp-Sig
EC	37,50	30	5,608	1,650	0,000
CC	15,24	28			

Table 6 provides information that creative thinking skills obtained z_{count} value equal to 5.608 > 1.650. This means that the initial hypothesis is rejected. The alternative hypothesis is accepted, so it can be concluded that EC's creative thinking skills are higher than CC's. This is in line with research conducted by Wartono et al. (2018) that PBL can improve students' learning achievement in physics and creative thinking skills. Almost all PBL phases can facilitate the improvement of students' physics creative thinking skills. Creativity involves higher-order cognitive thought processes that include innovative problem solving, which results in divergent thinking and the possibility of producing multiple solutions. This is in line with the policy pursued by the Ministry of Education in Singapore by promoting learning that helps all students discover their talents and develop a passion for lifelong learning. Encouraging the younger generation to think critically and creatively to create an environment as a place to experiment so that they excel in academics, arts, and sports (Keun & Hunt, 2006).

PBL practices develop creative thinking through brainstorming as they hypothesize and create new ways of learning. Im et al., (2015) states that as a cognitive function, the elements of creativity consisting of thinking, dreaming, having different perspectives, flexibility, fluency, originality, and enrichment greatly affect students' learning capacity and problem solving, as well as the development of their skills. These studies show that the PBL process contributes to the development of students' creative thinking skills (Huang et al., 2020).

Data on students' critical thinking skills is the value obtained from the test results after learning with PBL. The data description of students' critical thinking skills can be seen in Table 7.

Table 7. Description of the Value of Critical Thinking Skills

Classes	The Highest Score	The Lowest Score	The Average Score	Standard Deviation
EC	3	1	2	.64
CC	2	1	1	.50

Table 7 provides information that the average values between EC and CC are very different, namely 0.64 and 0.50. Furthermore, the initial ability data of students from both classes were tested for normality and homogeneity as a prerequisite for hypothesis testing. Based on the analysis prerequisite test, it can be seen that the distribution of the data from the two classes of posttest results is not normally distributed. Therefore, to test the research hypothesis, a nonparametric test is used. The selected nonparametric test is the U test or the Mann-Whitney test. The results of the hypothesis test of critical thinking skills in the experimental and control classes can be seen in Table 8.

Table 8. The Critical Thinking Skills Hypothesis Test Results

Classes	$\bar{x}$	N	Z_{count}	Z_{table}	Asymp-Sig
EC	35,50	30	0,497	1,650	0,000
CC	17,48	28			

Table 7 informs that the value of z_{count} is equal to 4.907 > 1.650. This means that the initial hypothesis is rejected, and the alternative hypothesis is accepted. It can be concluded that EC's critical thinking ability is higher than CC. According to data and analysis, the average value of students' creative thinking skills with PBL learning is higher than conventional learning. The results of data analysis with the U test or Mann-Whitney show that students' creative thinking ability taught with PBL is higher than students who are taught conventionally. The average value of students' critical thinking skills taught by PBL learning is higher than conventional learning in learning achievement data. The results of data analysis showed that the critical thinking ability of students who were taught PBL was higher than students who were taught conventionally. This is in line with the results of previous studies reporting that each stage of PBL can facilitate in increasing students' creativity (Ceyland, 2020) and students' critical thinking (Kardoyo et al., 2020). This can be seen from students being able to solve physics cases given by the teacher according to topics being studied and provide alternative solutions so that learning is more interesting and challenging. In addition, PBL is a tool in encouraging students' conceptual talents, establishing mental models of their problems, and presenting their knowledge in various formats, including pictures, diagrams, graphic organizers, and written words (Gallagher, 2015). Another thing that is in line with Birgili (2015) findings, PBL can guide students to see an idea analytically, not by starting at the identification stage but starting with a search and valid facts. The imagination ability possessed by students begins to be trained and honed so that it can be stored in long-term memory so that it encourages problem-solving and critical thinking.

PBL is a learning model oriented to a constructivist theoretical framework that leads to students' concepts for the better. The focus of PBL learning lies in the chosen problem so that it not only requires students to learn concepts related to the problem but also the scientific method to solve the problem (Hasanah et al., 2021). The PBL learning process carried out was very good. This can be seen from the students' increasing physics learning outcomes. PBL bridges teams and small groups to collaborate, find solutions and develop scientific concepts besides developing practical communication skills. Thus, students are forced to think independently and unite opinions (Isatunada & Haryani, 2021).

Conclusion

Implementing the problem-based learning model is proven to influence in improving students' creative and critical thinking skills on the topic of static fluid. In addition, the creative and critical thinking skills of students who are taught PBL are higher than students who are taught by conventional learning. Thus, PBL can be recommended in facilitating and improving students' creative and critical thinking skills on static fluid material. This research implies that teachers can design learning models that can sharpen students' HOTS. In addition, teachers can stimulate students to be more critical and creative in answering and solving physics problems completely.

References

Abbey, L., Dowsett, E., & Sullivan, J. 2017. Use of problem-based learning in the teaching and learning of horticultural production. *Journal of Agricultural Education and Extension*, 23(1):61–78.

Amira, T., Lamia, M., & Hafidi, M. 2019. *Learning Styles in a Collaborative Algorithmic Problem-Based Learning. The Review of Socionetwork Strategies,* 13:3-17.

Avvisati, F., Jacotin, G., & Vincent, L.S. 2014. Educating higher education students for innovative economies: what international data tell us. *Tuning Journal for Higher Education*, 1(1):223-239.

Bakar, R. 2018. The influence of professional teachers on Padang vocational school students' achievement. *Kasetsart Journal of Social Sciences*, 39(1):67–72.

Batlolona, J.R., Diantoro, M., Wartono, & Latifah, E. 2019. Creative thinking skills students in physics on solid material elasticity. *Journal of Turkish Science Education*, 16(1): 48–61.

Bechter, B.E., Dimmock, J.A., & Jackson, B. 2019. A cluster-randomized controlled trial to improve student experiences in physical education: Results of a student-centered learning intervention with high school teachers. *Psychology of Sport and Exercise*, 45(0):101553.

Birgili, B. 2015. Creative and critical thinking skills in problem-based learning enviroments. *Journal of Gifted Education and Creativy*, 2(2):71-80.

Bigozzi, L., Tarchi, C., Falsini, P., & Fiorentini, C. 2014. "Slow Science": Building scientific concepts in physics in high school. *International Journal of Science Education*, 36(13):2221–2242.

Ceylan, Ö. 2020. The effect of the waste management themed summer program on gifted students' environmental attitude, creative thinking skills and critical thinking dispositions. *Journal of Adventure Education and Outdoor Learning*, 1–13.

Dahlgren, M.A., & Dahlgren, L.O. 2002. Portraits of PBL: Students' experiences of the characteristics of problem-based learning in physiotherapy, computer engineering and psychology. *Instructional Science*, 30(2):111–127.

Dawilai, S., Kamyod, C., & Prasad, R. 2019. *Effectiveness Comparison of the Traditional Problem-Based Learning and the Proposed Problem-Based Blended Learning in Creative Writing: A Case Study in Thailand. Wireless Personal,* 118:1853–1867.

De Luca, R., Di Mauro, M., Naddeo, A., Onorato, P., & Rosi, T. 2020. Achilles overtakes the turtle: Experiments and theory addressing students' difficulties with infinite processes. *Physics Education*, 55(3):1-13.

Deubel, P. 2003. An investigation of behaviorist and cognitive approaches, 12(1):63–90. https://www.itma.vt.edu/courses/tel/resources/deubel(2003)_gagne_ID.pdf.

Dunsmuir, S., Frederickson, N., & Lang, J. 2017. Meeting current challenges in school psychology training: The role of problem-based learning. *School Psychology Review*, 46(4):395–407.

Estrada, L., Rodríguez, E., & Meléndez, A. 2018. Healthy choices with problem-based learning*. Journal of Physical Education, Recreation & Dance,* 89(1):55–57.

Eveillard, M., Pouliquen, H., Ruvoen, N., Couvreur, S., Krempf, M., Magras, C., & Lepelletier, D. 2017. Antibiotic exposure and bacterial resistance in human and veterinary medicine: A problem-based learning topic for Master's students. *FEMS Microbiology Letters*, 364(6):1–4.

Facione, N.C. & Facione, P.A. 1994. *Holistic Critical Thinking Scoring Rubric*. California: California Academic Press.

Foo, C.C., Cheung, B., & Chu, K.M. 2021. A comparative study regarding distance learning and the conventional face-to-face approach conducted problem-based learning tutorial during the COVID-19 pandemic. *BMC Medical Education*, 21(141):1-6.

Fidan, M. & Tuncel, M. 2019. Integrating augmented reality into problem based learning: The effects on learning achievement and attitude in physics education. *Computers and Education*, 142(0):1-19.

Gallagher, S.A. 2015. The role of problem-based learning in developing creative expertise*. Asia Pacific Education Review,* 16(2):225–235.

Günter, T. & Alpat, S.K. 2017. The effects of problem-based learning (PBL) on the academic achievement of students studying 'Electrochemistry.' *Chemistry Education Research and Practice*, 18(1):78–98.

Hasanah, Z., Pada, A.U.T., Safrida, Artika, W., & Mudatsir. 2021. Implementasi model problem based learning dipadu lkpd berbasis STEM untuk meningkatkan keterampilan berpikir kritis pada materi pencemaran lingkungan. *Jurnal Pendidikan Sains Indonesia*, 9(1):65-75.

Huang, N., Chang, Y., & Chou, C. 2020. Effects of creative thinking, psychomotor skills, and creative self-efficacy on engineering design creativity*. Thinking Skills and Creativity,* 37:1-10.

Im, H., Hokanson, B., & Johnson, K.K.P. 2015. Teaching creative thinking skills: a longitudinal study*. Clothing and Textiles Research Journal,* 33(2):129–142.

Isatunada, A. & Haryani, S. 2021. Development of science learning tools using the STEM approach to train problem solving ability and students activeness in global warming material. *Jurnal Pendidikan Sains Indonesia*, 9(3):363-375.

Jansen, I., Silkens, M.E.W.M., Stalmeijer, R.E., & Lombarts, K.M.J.M.H. 2019. Team up! Linking teamwork effectiveness of clinical teaching teams to residents' experienced learning climate. *Medical Teacher*, 41(12):1392–1398.

Kardoyo, Nurkhin, A., Muhsin, & Pramusinto, H. 2020. Problem-based learning strategy: its impact on students' critical and creative thinking skills. European *Journal of Educational Research*, 9(3):1141-1150.

Keun, L.L. & Hunt, P. 2006. *Creative dance: Singapore children's creative thinking and problem‐solving responses. Research in Dance Education,* 7(1):35–65.

Komasawa, N., Berg, B.W., & Minami, T. 2018. Problem-based learning for anesthesia resident operating room crisis management training. *PLoS ONE*, 13(11):1–10.

Leone, M. & Rinaudo, M. 2020. Should the history of physics be rated X A survey of physics teachers' expectations. *Physics Education*, 55(3):1-18.

Lin, W.L., Tsai, P.H., Lin, H.Y., & Chen, H.C. 2014. How does emotion influence different creative performances? The mediating role of cognitive flexibility. *Cognition and Emotion*, 28(5):834–844.

Lipsky, M.S., Cone, C.J., Watson, S., Lawrence, P.T., & Lutfiyya, M.N. 2019. Mastery learning in a bachelor's of nursing program: The Roseman University of Health Sciences experience. *BMC Nursing*, 18(1):1–9.

Macho, S.E. & Elejalde, García, M.J. 2013. Case study of a problem-based learning course of physics in a telecommunications engineering degree. *European Journal of Engineering Education*, 38(4):408–416.

Niederriter, J., Hovland, C., Hazelett, S., Whitford, M., Drost, J., Brown, D., Morgan, A., Kropp, D., Sanders, M., Gareri, M., Fosnight, S., Radwany, S., McQuown, C., & Ahmed, R. 2020. Using the Constructivist/Active Learning Theoretical Framework to develop and test a simulation-based interprofessional geriatric training curriculum. *Journal of Interprofessional Education and Practice*, 19(0):1-6.

Peters, M. 2015. Using cognitive load theory to interpret student difficulties with a problem-based learning approach to engineering education: A case study. *Teaching Mathematics and Its Applications*, 34(1):53–62.

Pease, M., & Kuhn, D. 2011. Experimental analysis of the efective components of problmbased learning. *Science Education*, 95:57–86.

Pincelli, M.M., Brustle, M., Formichella, M. del C., Perez-Millán, C., Palmieri, N., & Otranto, S. 2020. Peeping over Galileo's shoulders: Laying the foundations of heliocentrism in elementary school. *Physics Education*, 55(3):1-10.

Ramma, Y., Bholoa, A., Watts, M., & Nadal, P.S. 2018. Teaching and learning physics using technology: Making a case for the affective domain. *Education Inquiry*, 9(2): 210–236.

Ritter, S.M., Gu, X., Crijns, M., & Biekens, P. 2020. Fostering students' creative thinking skills by means of a one-year creativity training program. *PLoS One*, 15(3):1–18.

Sanson-Fisher, R.W. & Lynagh, M.C. 2005. Problem-based learning: a dissemination success story?. *Medical Journal of Australia,* 183(5):258–260.

Schmidt, H.G., van der Molen, H.T., te Winkel, W.W.R., & Wijnen, W.H.F.W. 2009. Constructivist, problem-based learning does work: A meta-analysis of curricular comparisons involving a single medical school. *Educational Psychologist*, 44(4):227–249.

Serdyukov, P. 2017. Innovation in education: what works, what doesn't, and what to do about it? *Journal of Research in Innovative Teaching & Learning*, 10(1):4–33.

Smeda, N., Dakich, E., & Sharda, N. 2014. The effectiveness of digital storytelling in the classrooms: a comprehensive study. *Smart Learning Environments*, 1(1):1–21.

Stanley, T. & Marsden, S. 2012. Problem-based learning: Does accounting education need it? *Journal of Accounting Education*, 30(3–4):267–289.

Sung, Y.T., Chang, K.E., & Liu, T.C. 2016. The effects of integrating mobile devices with teaching and learning on students' learning performance: A meta-analysis and research synthesis. *Computers and Education*, 94:252–275.

Tanner, K.D. 2013. Structure matters: Twenty-one teaching strategies to promote student engagement and cultivate classroom equity. *CBE Life Sciences Education*, 12(3):322–331.

Tasker, T.Q, & Herrenkohl, L.R. 2016. Using peer feedback to improve students' scientific inquiry. *Journal of Science Teacher Education*, 27(1):35–59.

Tatner, M. & Tierney, A. 2016. An extended, problem-based learning laboratory exercise on the diagnosis of infectious diseases suitable for large level 1 undergraduate biology classes. *Journal of Biological Education*, 50(1):54–60.

Tiwari, A., Lai, P., So, M., & Yuen, K. 2006. A comparison of the effects of problem-based learning and lecturing on the development of students' critical thinking. *Medical Education*, 40(6):547–554.

Tsivitanidou, O.E., Zacharia, Z.C., & Hovardas, T. 2011. Investigating secondary school students' unmediated peer assessment skills. *Learning and Instruction*, 21(4):506–519.

Torrance, E.P. 2006. Torrance Test of Creative Thinking. Ben-senville: Scholastic Testing Service.

Utriainen, J., Marttunen, M., Kallio, E., & Tynjälä, P. 2017. University applicants' critical thinking skills: the case of the finnish educational sciences. *Scandinavian Journal of Educational Research*, 61(6):629–649.

Wartono, Diantoro, M., & Batlolona, J.R. 2018. Influence of problem based learning model on student creative thinking on elasticity topics a material. Jurnal Pendidikan Fisika Indonesia, 14(1):32-39.

Woolfolk, A. 2016. *Educational psychology: developing learners with mylab education with enhanced pearson etext*, Loose-Leaf Version— Access Card Package (9th Edition). New York: Pearson College Div.

Xiao, F., Barnard-Brak, L., Lan, W., & Burley, H. 2019. Examining problem-solving skills in technology-rich environments as related to numeracy and literacy. *International Journal of Lifelong Education*, 38(3):327–338.

Yazar, S.B.B. 2015. Creative and critical thinking skills in problem-based learning environments. *Journal of Gifted Education and Creativity*, 2(2):71–71.

Young, S.J., Lee, D., Ramos, W., & Young, S.J. 2018. Examining problem-based learning in a recreation and sport law learning context sport law learning context. *Schole: A Journal of Leisure Studies and Recreation Education*, 32(2):124-134.

Yu, C., Beckmann, J.F., & Birney, D P. 2019. Cognitive flexibility as a meta-competency / Flexibilidad cognitiva como meta-competencia. *Estudios de Psicologia*, 40(3):563–584.