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PjBL Model assisted by Smartphone Sensors to Improve Critical Thinking Skills of Prospective Science Teachers

Prasetyo Listiaji[1], Risti Ayu Widianingrum[2], Anggita Ayu Ivanda Saputri[3], Nor Farahwahidah Abdul Rahman[4]
[1-3]Departement of Integrated Science, Universitas Negeri Semarang, Indonesia
[4]School of Education, Universiti Teknologi Malaysia, Malaysia

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Abstract

This research aims to analyze the improvement of the critical thinking skills of prospective science teachers after the implementation of smartphone-assisted PjBL and analyze the responses of prospective science teachers to the applied learning model. The research used an experimental model with a Nonequivalent Control Group Design. The research subjects were 2nd semester Science Education Program students in 2 classes of basic physics courses (experimental and control) as prospective science teachers. Data collection methods were test techniques for measuring critical thinking skills and questionnaire methods for determining student responses. Data analysis methods ware N-Gain analysis, independent sample t-test, and qualitative descriptive. The results showed a high increase in critical thinking skills in the experimental class, as indicated by an N-Gain score of 0.71. The results of the hypothesis test also showed that there was a significant difference between the post-test scores of the experimental and control classes. The PjBL model assisted by smartphone sensors also received a very good response from prospective science teacher students. The PjBL model assisted by smartphone sensors can be implemented to improve the critical thinking skills of prospective science teachers and can also be a reference for innovative learning models that align with the demands of technology-based 21st-century learning.

Keywords: applied learning model, critical thinking skills, project-based learning, prospective science teachers, smartphone sensors

Corresponding Author:
Ptasetyo Listiaji, Department of Integrated Science, Universitas Negeri Semarang, Indonesia
Email: p.listiaji@mail.unnes.ac.id

1. Introduction

The rapid development of the global world in the 21st-century requires special skills that everyone must be possessed. These skills are known as 21st-century or 4C skills, namely Critical Thinking, Collaboration, Communication, and Creativity. These skills are expected to keep pace with global world demand in the future. Teachers as educators are required to be able to give birth to a generation of nations that can compete in the revolutionary era 4.0 (Rahmatullah et al., 2022). One of the 21st-century skills that are very important to be trained by teachers to students is critical thinking. The importance of equipping critical thinking skills is that students are accustomed to facing challenges and solving problems by analyzing their thoughts to decide on a choice and draw conclusions so that quality graduates are printed and can compete against challenges (Liu et al., 2014). Critical thinking is a way for someone to improve the quality of the results of thinking using systematic techniques, ways of thinking, and generating intellectual thinking power in the ideas that are initiated (Lorencova, 2019).

According to Alatas (2014), students who have critical thinking skills will have the courage to express ideas, always have curiosity, be flexible, open-minded, honest, careful in making judgments, think, orderly, and sequentially in solving a problem, and never give up in finding optimal results. Therefore, critical thinking skills need to be empowered in the learning process. Mahanal et al. (2019) and Yamin et al. (2021) argue that the ability to think critically cannot arise in learning. Students need to be trained to use their thinking skills in learning so that they not only can memorize but also can think critically. A teacher cannot train critical thinking in his students if he does not have critical thinking skills (Ikhlas et al., 2021). Critical thinking skills can be trained in science learning; therefore, science teachers must not only be able to design learning that stimulates critical thinking, but they must also have high critical thinking skills (Demirhan & Koklukaya, 2014).

To prepare science teachers to have high thinking, a strategy for preparing Prospective science teachers at the university level is needed. Universities that print Prospective science teachers not only provide knowledge of science content, pedagogy, and technology but also must present a lecture atmosphere that can train 21st-century skills. Based on the results of research conducted by Fitriani et al. (2018) shows that critical thinking in Prospective science teachers is still relatively weak if it is based on The California Critical Thinking Disposition Inventory (CCTDI). However, there are not many studies that discuss how to improve the critical thinking of prospective science teachers. For example, Demiral (2018) research only reached the stage of investigating and measuring the critical thinking of prospective science teachers.

Prospective science teachers need to be trained to improve their critical thinking skills by provising lecture activities that can stimulate critical thinking skills. One of the learning models that can be offered is Project Based Learning (PjBL). Goodman and Stivers (2010) define PjBL as a teaching approach built on learning activities and real tasks that provide challenges for students related to everyday life to be solved in groups through a project (Bell, 2010; Wurarah et al., 2022). The characteristics of the PjBL model make students face concrete problems, find solutions, and work on projects in teams to overcome these problems (MacLeod & van der Veen, 2020). In the PjBL model, students not only understand the content but also develop skills in students how to play a role in society. Skills developed in PjBL include communication and presentation, organizational and time management, research and inquiry, self-assessment and reflection, group participation and leadership, and critical thinking skills (Kamerikar et al., 2020). Based on these characteristics, PjBL is undoubtedly very suitable to be applied to higher education learning, especially for the preparation of prospective science teachers.

Projects that can be developed in the lectures of prospective science teachers are projects in the form of science experiments. Through experimental activities, science teacher candidates can practice their critical thinking skills by solving problems related to the science phenomena being experimented on (Koray & Koksal, 2009). However, experimental activities in universities are still not running optimally because in the new normal era, the learning process still uses the blended concept where some activities are not carried out face-to-face, including practical activities (Gamage et al., 2020). Experimental activities generally use two methods; virtual experiments that use virtual laboratories and home experiments. The advantage of home experiments compared to virtual practicums is that students can still do actual experiments at home to train their skills better. However, home experiments require tools and materials that students need to prepare themselves (Kaps et al., 2021).

One tool that has the potential to be used in home experiments is a smartphone (Dahnuss et al., 2021). Smartphones have a variety of sensors such as acceleration sensors, magnetometers, light, sound, gyroscopes, pressure, etc. that can be used as tools when doing science practicum (Dahnuss et al., 2021; Pili & Violanda, 2018; Nuryadin & Hindawan, 2018). Many studies related to the use of smartphone sensors for science experiments have been carried out, such as momentum, oscillation, Atwood experiments, circular motion, analysis of compound concentrations, and measurement of respiratory rate (Dahnuss et al., 2021; Pili & Violanda, 2018; Nuryadin & Hindawan, 2018). However, these studies only arrived at experimental solutions, not to the stage of examining their effect on the ability of prospective science teachers, one of which is critical thinking.

Recent reasearch related to the implementation of PjBL to improve critical thinking skills have been carried out, but with research subjects ranging from elementary school to high school students (Duke et al., 2021; Firda & Sunarti, 2021; Putri et al., 2021), while this research took a state to improve the critical thinking skills of prospective science teachers. In addition, the recent PjBL implementation has not integrated much information technology in line with 21st century learning, such as the research of Baran et al. (2021) and Syukri et al. (2021) who used STEM-based PjBL. The implementation of PjBL in this study has distinction by integrating technology in experimental activities assisted by smartphone sensors. The use of smartphone sensors has the potential to be used in PjBL. Students who are prospective science teachers can be assigned simple project assignments regarding science experiments using smartphone sensors. Experiments can be done independently and easily at home. Through the PjBL model assisted by smartphone sensors, prospective science teacher students can train themselves to solve a practical science problem, design, and create a project to solve these problems, which of course, is possible to improve their critical thinking. Based on the potential of using PjBL assisted by smartphone sensors and the absence of research related to improving the critical thinking of prospective science teachers, it is necessary to conduct research on the implementation of PjBL assisted by smartphone sensors to improve the critical thinking skills of prospective science teachers. This research has two objectives; to analyze the improvement of the critical thinking skills of prospective science teachers after the implementation of smartphone assisted PjBL in science education lectures and to analyze the responses of prospective science teachers to the applied learning model.

2. Method

The research used was quantitative research, namely experimental research with a Nonequivalent Control Group Design. The research design was stated by Table 1. O_1 was the pre-test in the experimental class, O_2 was the post-test in the experimental class, O_3 was the pre-test in the control class, O_4 was the post-test in the control class, X was the treatment given to the experimental class, using a PjBL model assisted by smartphone sensor, Y was the treatment given to the control class, namely the direct instruction model assisted by a virtual laboratory.

The research was conducted at the Science Education Study Program, Universitas Negeri Semarang in the Even Semester of 2021/2022. The research subjects used were 2nd semester students who took basic physics courses selected in 2 classes (experimental and control). Each class consists of 25 prospective science teacher students.

Data collection methods were in the form of test methods and questionnaire methods. The test was used to measure the critical thinking skills of prospective science teachers. The questionnaire method was used to determine student responses to the lectures. Based on the data collection method used, this study used two instruments; test questions (pre-test and post-test) and student response questionnaire sheets. The test questions consisted of 15 essays adjusted to the indicators of critical thinking skills and cognitive level shown by the grid of questions in table 2.

Table 1. Research design

Group	*Pre-test*	Treatment	*Post-test*
Experiment	O_1	X	O_2
Control	O_3	Y	O_4

Table 2. Grid of Pre-Test and Post-Test Questions

Code of Indicator	Indicators of critical thinking ability (Ennis, 1996).	Number of questions	Cognitive Level					
			C1	C2	C3	C4	C5	C6
CTS 1	Able to formulate the main points of the problem	3						√
CTS 2	Able to reveal the facts needed to slove a problem	3			√			
CTS 3	Able to choose logical, relevant, and accurate arguments	3					√	
CTS 4	Able to detect bias based on different point of view	3				√		
CTS 5	Able to formulate the consequences of a statement taken as a decision	3						√

Note: CTS is code for critical thinking skill indicators, C1 (remembering), C2 (understanding), C3 (applying), C4 (analyzing), C5 (evaluating), and C6 (creating).

To determine the effect of PjBL model assisted by smartphone sensors to improve critical thinking skills, two data analysis methods were carried out. The data analysis were N-Gain analysis and hypothesis testing with independent sample t-test. The results of the N-Gain analysis were compared with the categories obtained by the G values (Table 3).

Meanwhile, the results of the t-test calculation were compared with the t_{table} value at a confidence level of 0.05 with dk = 50 – 2 = 48, so that the t_{table} = 1.677 is obtained. The design of the hypothesis is shown in Table 4.

Then, to analyze the response data of prospective science teacher students to lectures, a qualitative descriptive analysis was used from the results of the completed response questionnaire.

Table 3. G Value Categorization

Interval (G)	*Gain*
(G) ≥ 0,7	High
0,3 ≤ (G) ≤ 0,7	Medium
0,3 ≥ (G)	Low

Table 4. Hypothesis Design

Hypothesis	Information	Terms Accepted
Ho	The average results of critical thinking skills in the experimental class were the same as in the control class	$t_{count} < t_{table}$
Ha	The average result of critical thinking skills in the experimental class were greater than in the control class.	$t_{count} > t_{table}$

3. Result and Discussion

a. Improvement of the Critical Thinking Skills

The results of the average pre-test and post-test scores in the experimental and control groups are shown in Table 5. Based on Table 5, the N-Gain score in the experimental group was in the high category, while the N-Gain score in the control group was in the medium category. There was an improvemen of critical thinking skills in the experimental and control class, but the improvement in the experiment class was higher. Based on these data, the PjBL model assisted by smartphone sensors has a positively impact on critical thinking improvement skills of prospective science teachers. To find out how the impact of each critical thinking skills indicator is presented, the average pre-test and post-test scores that have been divided for each indicator (Table 6). N-Gain for each indicator is shown in Figure 1.

Based on table 6 and Figure 1, the experimental class obtained an improvement in critical thinking skills higher than the control class. In the experimental class the N-Gain value ranges from 0.62 to 0.72 in the medium and high categories, while in the control class the N-Gain value is in the range 0.32 to 0.58. In the experimental class N-Gain for indicators CTS 1, CTS 2, and CTS 3 obtained the medium category. In the CTS 1, CTS 2, and CTS 3 indicators, prospective science teacher students obtained higher pre-test scores than those in CTS 4 and 5. This was because in CTS 1 to CTS 3 students were assisted by the knowledge previously acquired in secondary school education. For example, in CTS 1, which is to formulate the main problems of Physics, this indicator is that students have been trained during secondary school education.

Table 5. The Results of Critical Thinking Skills in the Experimental and Control Group

Group	Pre-test	Post-test	N-Gain (G)
Experiment	55.28	86.56	0.71
Control	56.73	76.42	0.46

Table 6. Pre-Test and Post-Test Results for Each Critical Thinking Skill Indicators

Group	Indicators	Pre-test	Post-test
Experiment	CTS 1	68.61	88.12
	CTS 2	60.85	88.06
	CTS 3	49.71	84.28
	CTS 4	55.30	87.25
	CTS 5	41.95	85.08
Control	CTS 1	66.73	77,60
	CTS 2	62.32	75,26
	CTS 3	51.14	73,25
	CTS 4	56.68	78,16
	CTS 5	46.78	77,83

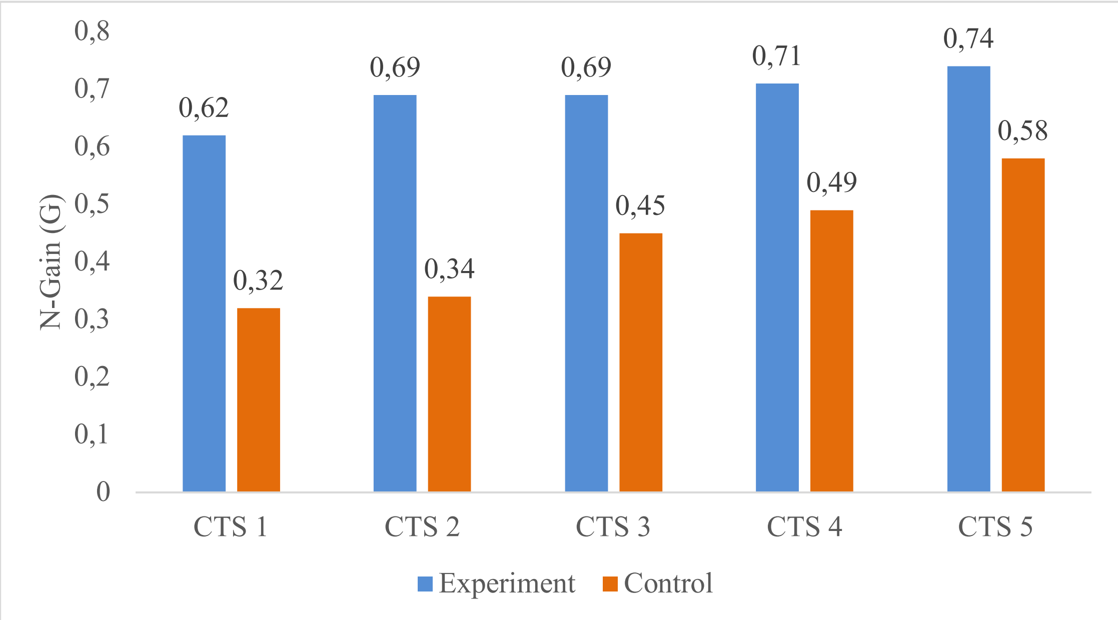

Figure 1. N-Gain for Each Critical Thinking Skill Indicator

Meanwhile, CTS 4 and CTS 5 obtained N-Gain in the high category. The PjBL model trains students to detect bias in different perspectives (CTS 4) through one of the learning experience evaluation syntaxes (Sasson et al., 2018). Through the evaluation of learning experiences, each prospective science teacher presents a project report, other students provide feedback, and conclude the project results together with the lecturer (Dimmitt, 2017). This learning syntax will expand knowledge from various points of view so that it will be able to detect biases that occur when developing projects. PjBL assisted by smartphone sensors, can also train students to formulate the consequences of a statement taken as a decision (CTS 5).

CTS 5 was obtained by students when conducting an experiment to make a simple basic physics project. In this activity, students choose the suitable smartphone sensor to use so that for each sensor selection, students can formulate the consequences of the data obtained. Each sensor on a smartphone has a different level of accuracy and precision so that students can analyze the consequences of the data from the project experiments that have been carried out. This activity is carried out in one of the PjBL syntaxes, namely developing projects. In this learning syntax, students do projects according to a schedule, record each stage, and discuss problems that arise during project completion with the lecturer (Kokotsaki, 2016).

In the control class, The improvement of critical thinking skills for each indicator is the medium category. This shows that learning using direct instruction assisted by virtual laboratories can also improve critical thinking skills but not significantly. This is because, the direct instruction model do not have learning syntax that focuses to improve critical thinking skills (Yeh, 2009). In the use of virtual laboratories, prospective science teacher students are also not trained to do acrtual experiments, so that the data obtained are ideal. This makes it difficult for students to analyze the problems that occur when experiments are carried out, students also cannot analyze errors that occured from various points of view when conducting experiments (Santyasa et al., 2019). The learning experience is also lacking because students do not practice the science experiment directly (Oldov et al,, 2012).

In order to test the significance of the influence of the PjBL model assisted by smartphone sensors on improving critical thinking skills, a hypothesis test was carried out using an independent sample t-test. The scores compared are the post-test scores of the experimental and control classes. The t-test was used because the post-test scores in the experimental and control classes were normally distributed from the results of the normality test. The results of the t-test using SPSS are shown in table 7.

Based on the results of the t-test analysis, it shows that t_{count} = 4,873 or greater than t_{table}, so that the alternative hypothesis (Ha) is accepted or indicates that there is a significant difference between the scores of critical thinking skills in the experimental class and in the control class. The score of critical thinking skills in the experimental class is higher than in the control class, so that the results of this hypothesis test are in line with the N-Gain analysis. In project-based learning, prospective science teacher students are trained to formulate projects from the esensial question stage, design projects, develop schedules, create projects, monitor projects, test results, and evaluate learning experiences. At the esensial question stage, prospective science teacher students practice formulating problem points (CTS 1) (Hofstein & Kind, 2012), when designing projects, students are also trained to reveal the facts needed in solving a problem choosing logical, relevant, and accurate arguments in designing projects (CTS 3 and CTS 4) (Cortazar et al., 2021). In project monitoring activities, testing results, and evaluating learning experiences, students are trained to detect bias based on different points of view from teachers and other students (CTS 4) and to formulate consequences of a step taken when developing a project (CTS 5). The consequence in question is the selection of the smartphone sensor used. This allows students to analyze how it impacts the project results. Another advantage of using smartphone sensors in experimental projects is that students can do it easily and attractively. Student interest in learning will also support the improvement of critical thinking skills (Nelson & Crow, 2014). The results of experimental projects using smartphone sensors will be more accurate.

Table 7. T-Test Eesult Using SPSS

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Skor	Equal variances assumed	1.936	.171	4.873	48	.000	10.160	2.085	5.968	14.352
	Equal variances not assumed			4.873	45.558	.000	10.160	2.085	5.962	14.358

b. Responses of Prospective Science Teachers

The responses of prospective science teacher students to PjBL model assisted by smartphone sensors were analyzed using a Linkert scale with a rating of 1 to 5. The results of student responses to learning are shown in Figure 2. The PjBL model assisted by smartphone sensors received a very good rating on attractiveness and fun, understanding of the material, practicality, and usefulness for prospective science teachers. In the attractiveness and fun aspect, students feel enthusiastic and interested in the learning model because it makes the development of challenging projects (Chiang & Lee, 2016). Students also feel that they understand the material better because the project is carried out as an experiment, so concrete knowledge can be obtained from the experimental results (Husnaini & Chen, 2019). The use of sensors on smartphones as a tool for science experiment projects is also considered practical because it can be done easily, and students can repeat it independently at home with their smartphone (Pili & Violanda, 2018). The application of a project-based learning model assisted by smartphone sensors is also helpful for prospective science teachers because it can provide for future learning references that align with technology-based 21st-century learning.

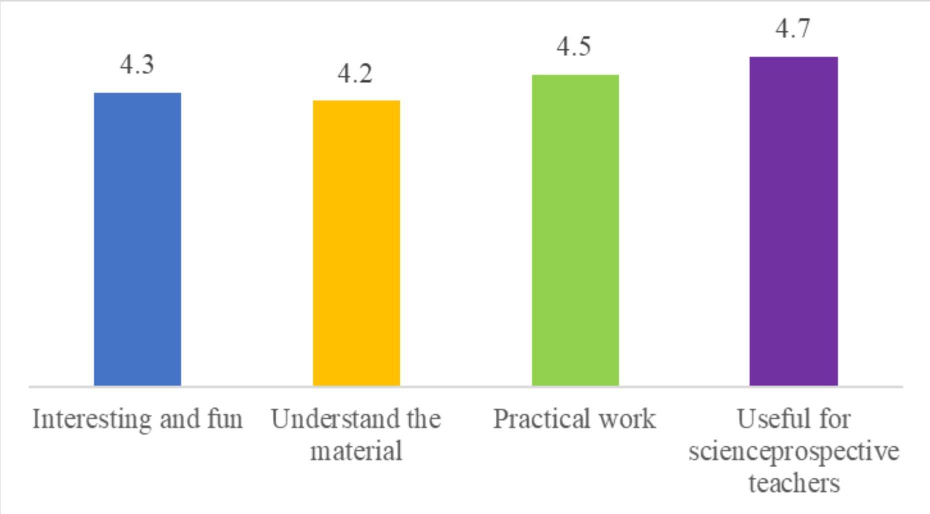

Figure 2. Responses of Prospective Science Teacher Student

4. Conclusion

The implementation of a PjBL model assisted by smartphone sensors can improve the thinking skills of prospective science teacher students as indicated by an improvement of critical thinking skills in the experimental class, obtaining an N-Gain score of 0.71 or high category. The hypothesis test result also showed a significant difference between the scores of critical thinking skills in the experimental and control classes. The applied learning model received a very good response from prospective science teacher students in terms of attractiveness and fun, understanding of the material, practicality, and usefulness for prospective science teachers. Project-based learning models assisted by smartphone sensors can be an offer to be applied at the higher education level, especially to prepare prospective science teachers to have good critical thinking skills, and can also be a reference for learning models that are in line with the demands of technology-based 21st-century learning.

5. References

Alatas, F. (2014). The relationship between concept understanding and critical thinking skills through the Treffinger learning model in basic physics courses. *Education*, *6*(1), 87-96.

Baran, M., Baran, M., Karakoyun, F., & Maskan, A. (2021). The influence of project-based STEM (PjbL-STEM) applications on the development of 21st century skills. *Journal of Turkish Science Education*, *18*(4), 798-815.

Bell, S. (2010). Project-based learning for the 21st century: Skills for the future. *The clearing house*, *83*(2), 39-43.

Chiang, C. L., & Lee, H. (2016). The effect of project-based learning on learning motivation and problem-solving ability of vocational high school students. *International Journal of Information and Education Technology*, *6*(9), 709-712.

Cortázar, C., Nussbaum, M., Harcha, J., Alvares, D., López, F., Goñi, J., & Cabezas, V. (2021). Promoting critical thinking in an online, project-based course. *Computers in Human Behavior*, *119*, 106705.

Dahnuss, D., Marwoto, P., Iswari, R. S., & Listiaji, P. (2021, June). Marbles and smartphone on physics laboratory: an investigation for finding coefficient of restitution. In *Journal of Physics: Conference Series* (Vol. 1918, No. 2, p. 022005). IOP Publishing.

Demirhan, E., & Köklükaya, A. N. (2014). The Critical Thinking Dispositions of Prospective Science Teachers. *Procedia-Social and Behavioral Sciences*, *116*, 1551-1555.

Demiral, U. (2018). Examination of Critical Thinking Skills of Preservice Science Teachers: A Perspective of Social Constructivist Theory. *Journal of Education and learning*, *7*(4), 179-190.

Dimmitt, N. (2017, September). The power of Project Based Learning: Experiential Education to Develop Critical Thinking Skills For University Students. In *CBU International Conference Proceedings* (Vol. 5, pp. 575-579).

Duke, N. K., Halvorsen, A. L., Strachan, S. L., Kim, J., & Konstantopoulos, S. (2021). Putting PjBL to the test: The impact of Project-Based Learning on Second Graders' Social Studies And Literacy Learning and Motivation in low-SES school settings. *American Educational Research Journal*, *58*(1), 160-200.

Ennis, R. H. (1996). Critical thinking dispositions: Their Nature and Assessability. *Informal logic*, *18*(2).

Firda, S. U., & Sunarti, T. (2022). The Learning Implementation of Project Based Learning (PjBL) to Analyze Students' 4C Skills Ability. *Prisma Sains: Jurnal Pengkajian Ilmu dan Pembelajaran Matematika dan IPA IKIP Mataram*, *10*(3).

Fitriani, H., Asy'Ari, M., Zubaidah, S., & Mahanal, S. (2018, November). Critical Thinking Disposition of Prospective Science Teachers at IKIP Mataram, Indonesia. In *Journal of Physics: Conference Series* (Vol. 1108, No. 1, p. 012091). IOP Publishing.

Gamage, K. A., Wijesuriya, D. I., Ekanayake, S. Y., Rennie, A. E., Lambert, C. G., & Gunawardhana, N. (2020). Online delivery of teaching and laboratory practices: Continuity of university programmes during COVID-19 pandemic. *Education Sciences*, *10*(10), 291.

Husnaini, S. J., & Chen, S. (2019). Effects of Guided Inquiry Virtual And Physical Laboratories on Conceptual Understanding, Inquiry Performance, Scientific Inquiry Self-Efficacy, and Enjoyment. *Physical Review Physics Education Research*, *15*(1), 010119.

Hofstein, A., & Kind, P. M. (2012). Learning in and from Science Laboratories. *Second international handbook of science education*, 189-207.

Ikhlas, M., Kuswanto, K., Sakunti, S. R., Debi, M. R., & Collantes, L. M. (2021). A Sequential Explanatory Investigation in using ICTs on Arabic Language and Islamic Values Education: Teacher-Students Perspective. *Indonesian Journal on Learning and Advanced Education (IJOLAE)*, *3*(3), 153-167.

Kamerikar, U., Patil, M. S., & Watharkar, S. R. (2020). Project Based Learning-An Innovative approach to enhance higher order skills. *Journal of Engineering Education Transformations*, *33*(3), 92-97.

Kaps, A., Splith, T., & Stallmach, F. (2021). Implementation of Smartphone-Based Experimental Exercises for Physics Courses at Universities. *Physics Education*, *56*(3), 035004.

Koray, Ö., & Köksal, M. S. (2009, April). The Effect of Creative and Critical Thinking Based Laboratory Applications on Creative and Logical Thinking Abilities of Prospective Teachers. In *Asia-Pacific Forum on Science Learning & Teaching* (Vol. 10, No. 1).

Liu, O. L., Frankel, L., & Roohr, K. C. (2014). Assessing Critical Thinking in Higher Education: Current State and Directions for Next-Generation Assessment. *ETS Research Report Series*, *2014*(1), 1-23.

Lorencová, H., Jarošová, E., Avgitidou, S., & Dimitriadou, C. (2019). Critical Thinking Practices in Teacher Education Programmes: a systematic review. *Studies in Higher Education*, *44*(5), 844-859.

MacLeod, M., & van der Veen, J. T. (2020). Scaffolding interdisciplinary project-based learning: a case study. *European journal of engineering education*, *45*(3), 363-377.

Mahanal, S., Zubaidah, S., Sumiati, I. D., Sari, T. M., & Ismirawati, N. (2019). RICOSRE: A Learning Model to Develop Critical Thinking Skills for Students with Different Academic Abilities. *International Journal of Instruction*, *12*(2), 417-434.

Nelson, L. P., & Crow, M. L. (2014). Do Active-Learning Strategies Improve Students' Critical Thinking?. *Higher Education Studies*, *4*(2), 77-90.

Nuryadin, B. W., & Hindawan, I. (2018). Impulse Measurement and Analysis Using A Smartphone Accelerometer. *Physics Education*, *54*(1), 015024.

Pili, U., & Violanda, R. (2018). Measuring Average Angular Velocity with A Smartphone Magnetic Field Sensor. *The Physics Teacher*, *56*(2), 114-115.

Putri, R. K., Bukit, N., & Simanjuntak, M. P. (2021, January). The Effect of Project Based Learning Model's on Critical Thinking Skills, Creative Thinking Skills, Collaboration Skills, & Communication Skills (4C) Physics in Senior High School. In *6th Annual International Seminar on Transformative Education and Educational Leadership (AISTEEL 2021)* (pp. 323-330). Atlantis Press.

Rahmatullah, A.S., Mulyasa, E., Syahrani, S., Pongpalilu, F. and Putri, R.E., 2022. Digital era 4.0: The contribution to education and student psychology. *Linguistics and Culture Review*, *6*, pp.89-107.

Santyasa, I. W., Santyadiputra, G. S., & Juniantari, M. (2019, August). Problem-Based Learning Model Versus Direct Instruction in Achieving Critical Thinking Ability Viewed from Students' Social Attitude in Learning Physics. In *1st International Conference on Education Social Sciences and Humanities (ICESSHum 2019)* (pp. 633-644). Atlantis Press.

Sasson, I., Yehuda, I., & Malkinson, N. (2018). Fostering the Skills of Critical Thinking and Question-Posing in a project-based learning environment. *Thinking Skills and Creativity*, *29*, 203-212.

Syukri, M., Yanti, D., Mahzum, E., & Hamid, A. (2021). Development of a PjBL Model Learning Program Plan Based on A Stem Approach To Improve Students' Science Process Skills. *Jurnal Penelitian Pendidikan IPA*, *7*(2), 269-274.

Yamin, M., Saputra, A., & Deswila, N. (2021). Enhancing Critical Thinking in Analyzing Short Story "The Lazy Jack" Viewed from Identity Theory. *Indonesian Journal on Learning and Advanced Education (IJOLAE)*, *3*(1), 30-39.

Wurarah, M., Yermia, M. S., & Sumampouw, H. M. (2022). Mangrove Biodiversity of Bunaken National Park in Project-Based Learning to Improve Students' Competitive Skills during the COVID-19 Pandemic. *Jurnal Pendidikan Progresif*, *12*(2), 647-659.

Yeh, Y. C. (2009). Integrating e-learning into the Direct-instruction Model to enhance the effectiveness of critical-thinking instruction. *Instructional Science*, *37*(2), 185-203.