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Research Article

Influence Of Iot-Based Problem Based Learning Model To Increase Problem Solving Abilities Physics Students

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Abstract: This study aims to comprehensively examine the influence of the Problem-Based Learning (PBL) model integrated with the Internet of Things (IoT) on enhancing students' problem-solving abilities in physics education. The integration of IoT into PBL is seen as a progressive approach to address the growing demand for innovative instructional strategies that promote higher-order thinking skills. A quantitative approach was adopted, utilizing a quasi-experimental design with a pretest-posttest nonequivalent control group format to assess the effectiveness of the intervention. The participants were 25 undergraduate physics students from the University of West Sulawesi, selected through saturated sampling due to the limited population size. To evaluate students' problem-solving skills, data were collected using structured written tests designed around five key indicators: understanding the problem, describing the problem, planning the solution, executing the solution, and evaluating the results. Prior to hypothesis testing, normality of the data was assessed using the Kolmogorov-Smirnov test, followed by paired sample t-tests with IBM SPSS Statistics 23 to determine the significance of differences in pretest and posttest scores. The findings revealed a statistically significant improvement in students' problem-solving skills following the implementation of the IoT-based PBL model, with results showing significance at the 5% level and gain scores classified as effective. These outcomes demonstrate the potential of the PBL-IoT integration to foster critical thinking and improve educational quality. Therefore, the implementation of this instructional model is recommended for physics educators seeking to enhance student engagement, problem-solving proficiency, and learning outcomes through the integration of emerging technologies.

Keywords: Critical thinking; Higher education; Internet of Things (IoT); Physics education; Problem-Based Learning.

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1. Introduction

Higher education, especially in physics, requires students to have high critical thinking and problem solving skills. These abilities are very important in understanding abstract physics concepts and applying them in various real-life contexts. However, the reality in the field shows that many students still experience difficulties in solving physics problems independently and systematically. This is due to the conventional learning method, where students receive more information passively without any challenge to explore and solve problems independently.

A major challenge in physics education lies in the lack of a bridge between theory and real-world practice. At the university level, physics learning tends to emphasise the mastery of abstract concepts without enough space for students to explore independently or hone problem-solving skills in the context of everyday life. Expository learning methods that focus on one-way delivery of material by lecturers are often unable to build deep understanding, and limit students' ability to apply physics theories to concrete situations. Research shows that most freshmen have experience with decision-making in physics practicum, which suggests that introductory courses should include more open-ended tasks to develop scientific and critical thinking skills [1]. These findings emphasise the importance of balancing theoretical knowledge with practical problem-solving experiences in physics education.

One approach that can be applied to overcome this problem is the Problem Based Learning (PBL) model. This learning model emphasises problem solving as the main focus in the learning process, so students are encouraged to think analytically, work collaboratively, and find solutions based on a deep understanding of concepts. In contrast to conventional methods, PBL provides opportunities for students to learn through active exploration and investigation.

Recent studies have explored various approaches to improve physics problem solving skills in students. One approach that has proven effective is exploratory learning where students first try to solve problems before getting explanations from lecturers. This method is proven to improve learning outcomes, especially in university-level online physics courses [2]. In addition, the use of research-based curriculum materials can help bridge the gap between traditional teaching methods and more innovative approaches. In this regard, gender differences have also been found to influence students' problem-solving strategies [3]. Developing expertise in physics problem solving requires not only understanding of concepts, but also good organisation of knowledge, management of cognitive load, and improvement of metacognitive skills - the ability to be aware of and regulate one's own thinking [4]. PBL significantly improves students' ability to solve physics problems. This was demonstrated in a study involving high school students learning about simple machines [5].

Various studies have shown that PBL improves problem-solving ability [5], critical thinking skills, and teamwork [6]. A systematic review revealed that PBL has a positive impact on academic achievement, attitude towards physics, and various cognitive skills [7]. However, traditional learning methods may be more effective for individual learning and acquisition of theoretical knowledge [5]. Integration of technology with inquiry-based learning has also proven successful in developing 21st century skills among physics students [8]. These findings suggest that a balanced approach combining PBL with technology integration can be highly effective in physics education. Educators are encouraged to adopt learner-centred methods to enhance problem-solving abilities and prepare them to face real-world challenges [5].

Along with the development of technology, the utilisation of Internet of Things (IoT) in physics learning becomes an attractive alternative. IoT allows students to access and analyse data in real-time, conduct technology-based experiments, and connect physics concepts with real-world applications. The integration of IoT-based PBL is believed to provide a more interactive and contextual learning experience, thus improving students' ability to solve problems more effectively.

The integration of Internet of Things (IoT) technology with the PBL approach in engineering education has been shown to increase student motivation and practical skill development [9]. This combination of PBL and IoT allows students to work on complex real-world problems, encourages interdisciplinary collaboration, and better prepares them for industry challenges. Overall, these studies suggest that PBL, especially when combined with emerging technologies such as IoT, can significantly improve student engagement and learning outcomes in physics and related fields.

Recent studies highlight the integration of the Internet of Things (IoT) and problem-based learning (PBL) in education, particularly in engineering and science. This approach combines theories of cognitivism, constructivism, and experiential learning to enhance student engagement and skill development. IoT-based PBL allows students to conduct virtual experiments, access real-time data, and collaborate in solving complex problems [9], [10]. The implementation of IoT in education, called Internet of Educational Things (IoET), offers better learning experience and operational efficiency [10].

Active learning strategies, such as group projects and peer review, have been successfully used to introduce IoT concepts and encourage student engagement [11]. These approaches have shown a positive impact on critical thinking skills and interest in learning [12]. Overall, IoT-based PBL models show potential to transform traditional teaching methods and prepare students for real-world applications across multiple disciplines [9]–[11]. This study aims to analyse the effect of IoT-based Problem Based Learning model on improving physics students' problem solving skills. With this research, it is expected to find a more effective and innovative learning model in improving the quality of physics education in higher education.

2. Theoretical Studies

PBL or project-based learning is a learning model that makes the problem as a starting point to gather and integrate knowledge based on real experiences that students experience in daily activities. This model is specifically designed to be applied to complex problems, which require learners to investigate and understand them deeply [13]. PBL is an effective learning approach to mould learners into critical, independent and solutive thinkers. By placing real problems as the starting point of learning, PBL encourages students to actively seek information, analyse, and solve problems collaboratively [14]. This method not only emphasises on mastering the material, but also on developing 21st century skills such as communication, teamwork, and decision-making. Thus, PBL becomes a relevant and transformative learning strategy in preparing students to face challenges in the real world [15].

This approach is based on the theories of cognitivism, constructivism, information processing, and experiential learning. Thus, students not only passively receive information but also build their own understanding through direct experience. The IoT-based PBL model allows students to conduct virtual experiments, access real-time data, and collaborate in solving complex problems [16].

According to [10] Internet of Things (IoT) is a revolutionary concept that connects various physical objects through the internet, enabling them to exchange data and act automatically without human intervention. In the context of education, particularly learning, IoT presents a major transformation by expanding access, improving efficiency, and creating interactive and contextualised learning experiences [9]. The Internet of Things (IoT) is a network of physical devices interconnected via the internet, enabling communication and data exchange without direct human interaction. These devices are equipped with sensors, software, and other technologies that allow them to collect and share data [17]. Examples include smart household devices, autonomous vehicles, and industrial sensors. The main goals of IoT are to improve operational efficiency, provide deeper insights through real-time data analysis, and improve quality of life through better automation and control.

In the context of physics education, the Internet of Things (IoT) refers to the integration of physical devices equipped with sensors and communication technologies into the learning process, enabling real-time data collection and analysis through the internet network. The application of IoT in physics learning allows students to conduct experiments with digitally connected props, allowing them to observe physical phenomena directly and analyse the data obtained efficiently. For example, the development of IoT-based Newton's law II teaching aids allows students to understand the concept through hands-on practice with the support of technology [18].

The application of IoT in learning enables the use of smart appliances in classrooms, interactive distance learning, scientific data collection through sensors, location-based learning, smart labs, and game-based education. This all opens up great opportunities to encourage student creativity, collaboration and motivation to learn. IoT also plays an important role in training students' problem-solving skills [19]. Students can collect and analyse real-time data, perform monitoring and prediction, develop automation systems, collaborate digitally, and conduct virtual simulations and experiments. All of these enrich the learning process and encourage them to become resilient, creative, and adaptive problem solvers to technological changes.

According to [17] IoT in this context, education has three main perspectives: school management, teachers, and students. In terms of school management, IoT plays an important role in improving operational efficiency, from automatic monitoring of building facilities, sensor-based security systems, to more measurable resource management. For teachers, IoT becomes a tool that supports a more personalised and data-driven teaching process. Examples include the use of automated attendance tracking systems, smart learning devices, and real-time student performance analysis to identify individual learning needs. Meanwhile, for students, IoT opens up opportunities for more contextualised and interactive learning. By utilising smart devices, digital simulations, and location-based learning, students can experience a more meaningful and real-world learning process. The integration of IoT in education ultimately has great potential to create a smarter learning ecosystem that is relevant to the challenges of the times.

3. Research Methods

This research applies a quantitative approach with a quasi-experiment design, utilising groups that have formed naturally [20], [21]. The main objective is to examine the effect of the Internet of Things (IoT)-based Problem Based Learning model on improving students' problemsolving skills in physics.

This study uses a design, namely pretest-posttest Nonequivalent Control Group Design, One-Group Pretest-Posttest is a form of pre-experimental research involving one group of subjects who are given certain treatments. In this design, measurements are taken twice: before treatment (pretest) and after treatment (posttest). The aim is to evaluate the changes that occur due to the treatment by comparing the results of the pretest and posttest posttest [22], [23].

Table 1. Research Desing

Pretest	Perlakukan	Posttest
Q1	T	Q2

Description

Q1 : Pretest to determine the initial ability of students on problem solving

T : Treatment with IoT-based PBL

Q2 : Final test results of students' problem solving skills with PBL

The population in this study were 25 students of the Physics Department of West Sulawesi University. In the context of research with a relatively small population, 25 students, the use of saturated sampling is an appropriate approach [22]. Saturated sampling is a sampling technique in which all members of the population are used as research samples. This technique is often applied when the population size is less than 30 individuals, making it possible to collect data from the entire population without the need to take a random sample.

In this study, data analysis was conducted using IBM SPSS Statistics 23 software. Descriptive analysis was applied to present the raw data in the form of frequency distribution tables and histogram graph visualisation, making it easier to understand the characteristics of the data obtained. For parametric inferential statistical analysis, paired sample t-test was used to compare two means of the same group at two different times or two different conditions [24], [25]. Before conducting the t-test, it is important to ensure that the data is normally distributed, as recommended by Sawilowsky and Hillman [26]. Therefore, a normality test was performed using the Kolmogorov-Smirnov test with a significance level of 0.05. If the significance value is more than 0.05, then the data is considered normally distributed; otherwise, if it is less than 0.05, the data is considered not normally distributed. Furthermore, hypothesis testing was conducted using the t-test with a significance level of 5%.

Data was collected using a written test by determining indicators of problem solving ability in the physics field of study with indicators including; (1) understanding the problem (focus the problem) this stage involves forming a mental picture of the problem situation. Students are expected to identify the objects involved, the relationship between objects, and the information provided. Sketching or diagramming is often used to visualise and clarify understanding of the problem; (2) describing the problem relates the situation to relevant physics concepts. This includes identifying applicable physics principles or laws, as well as determining the parameters and variables involved in the problem; (3) design the problem solution (plan the solution) plan the steps of the solution based on the identified physics principles. This involves selecting appropriate formulas or equations and strategies to link known variables with unknown variables; (4) test the problem solution. (execute the solution) perform the planned calculations or procedures systematically. Rigour in following the planned steps is essential to ensure accurate results; (5) evaluate the solution of the problem (evaluate the solution) review the results obtained to ensure consistency and reasonableness with the context of the problem. Students need to check whether the solution found makes physical sense and fits the given initial conditions.

4. Research Results

Data analysis results with indicators to measure the problem solving ability of students majoring in physics with indicators of understanding the problem, describing the problem, designing solutions, testing solutions, and evaluating solutions this data includes mean, std.

error of mean, median, mode, std. deviation, variance, range, minimum, maximum, sum can be seen in the following table.

Table 2. Descriptive Data of Student Problem Solving Ability

Deskriptif	Pretest	Postest
N	25	25
Mean	68,00	84,08
Std. Error of Mean	1,153	,838
Median	70,00	85,00
Mode	60a	87
Std. Deviation	5,766	4,192
Variance	33,250	17,577
Range	22	15
Minimum	56	75
Maximum	78	90
Sum	1700	2102

Table 2. presents descriptive data for evaluating the problem solution with a sample of 25 participants. Based on the results obtained, the mean value for the pretest was 68.00, while the posttest mean value increased to 84.08, indicating a significant improvement after the intervention or learning. The standard error of mean in the pretest was 1.153, while in the posttest it decreased to 0.838, reflecting an increase in the accuracy of the mean estimation in the posttest. The pretest median was 70.00 and the posttest was 85.00, while the mode on the pretest was 60 and on the postest was 87, indicating the most frequently occurring value in the data.

In terms of variability, the standard deviation on the pretest was 5.766, which was greater than that on the posttest which had a standard deviation of 4.192. This suggests that although the spread of participants' scores was greater on the pretest, after the intervention, the spread of participants' scores became more centralised. The variance at pretest was 33.250, while at postest it decreased to 17.577, indicating a reduction in the degree of dispersion of the data after the intervention. The range between the highest and lowest scores on the pretest was 22 (from 56 to 78), while on the posttest the range was smaller at 15 (from 75 to 90). The total score for the pretest was 1700, and for the posttest was 2102, indicating a significant accumulated increase in scores. Overall, this descriptive data shows a clear improvement in participants' problem-solving abilities after the learning or intervention.

Table 3. Normality Test

Variabel	Statistic	df	Sig.	Description
Problem solving pretest	,962	25	,455	Significant
Problem solving posttest	,939	25	,137	Significant

Based on the results of the normality test presented in Table 3, the analysis of the pretest and posttest data of students problem solving ability shows that both sets of data are normally distributed. The Kolmogorov-Smirnov statistical value for the pretest is 0.962 with a significance of 0.455, while for the posttest is 0.939 with a significance of 0.137. Since both significance values are greater than 0.05, it can be concluded that the pretest and posttest data fulfil the assumption of normality. This allows the use of parametric statistical analysis techniques for further hypothesis testing related to students problem solving skills.

Table 4. Paired sample t test of problem solving

Class	N	df	Nilai		*Sig*	Conclusion
			t_{hitung}	t_{tabel}		
Postest - Pretest	25	24	11,964	1.711.	0.00	Signifikan

Based on the results of the paired sample t-test presented in Table 4.27, the analysis of pretest and posttest data on students' problem-solving skills showed significant differences before and after treatment. With a sample size of 25 students and a degree of freedom (df) of 24, the calculated t value is 11.964. This value far exceeds the t table of 1.711 at the 0.05 significance level. In addition, the significance value (Sig.) of 0.00, which is smaller than 0.05, indicates that the difference is statistically significant. Thus, it can be concluded that there is a significant increase in students problem solving ability after the treatment. These results indicate that the interventions carried out, whether in the form of learning strategies, use of media, or certain approaches, have a positive impact on improving students' ability to solve problems. This finding is evidence that the treatment given is effective and worthy of consideration in the next learning process.

Table 5. Results of N Gain analysis of Problem Solving

N	Pretest	Postest	N Gain	Category
25	68	84,08	0.70	Effective

Based on Table 5, it is known that the average student pretest score of 68 increased to 84.08 in the posttest after treatment. This increase resulted in an N-Gain value of 0.70 which is included in the high or effective category. Referring to the gain interpretation criteria, the N-Gain value ≥ 0.70 indicates that the learning provided is classified as very effective in improving students' abilities. This means that the interventions applied during the learning process in the form of models, media, and certain strategies have succeeded in having a positive impact on improving students' problem solving skills. This finding is in line with the results of the previous paired sample t-test which showed a significant difference between the pretest and posttest. Thus, it can be concluded that the treatment given not only has a statistical impact, but also has a high effectiveness in encouraging the improvement of students' thinking and problem solving skills.

5. Discussion

In physics education, PBL has shown positive effects on academic achievement, critical thinking, and problem-solving ability [7]. Integrating IoT in education can enhance the learning experience and provide real-time insight into student performance [10]. Blended learning approaches can reinforce learning and promote learner-centred education [27]. These studies emphasise the importance of aligning teaching methodologies with learners' needs and leveraging technology to improve educational outcomes across different disciplines.

In organising Internet of Things (IoT) learning, important variables should be considered, such as technological readiness, which measures the extent to which existing infrastructure and systems support the implementation of IoT, digital understanding, which describes the ability of lecturers and students to operate advanced technology, and managerial support, which shows how much the role of university management in facilitating the adoption of this technology [28].

These results are in line with a study [29] showing the effectiveness of problem-based learning (PBL) in improving students' problem-solving and critical thinking skills across various disciplines. These studies utilised various statistical methods, including paired and independent sample t-tests, MANOVA, and N-gain analyses, to demonstrate the effectiveness of PBL interventions [29]–[31]. The findings consistently support PBL as an effective approach to developing essential skills across educational levels and subject areas.

In understanding and describing the problem, participants showed a clear improvement in identifying and explaining the problem more systematically. Before the intervention, many participants had difficulty in describing the problem in a structured way. However, after participating in PBL-IoT-based learning, they became more capable in detailing the problem and understanding the interrelationships between concepts better.

At the stage of designing and testing solutions, participants showed progress in critical and analytical thinking. They were more active in exploring various possible solutions and more skilful in applying relevant concepts to solve the given problem. In addition, they were also able to test the designed solutions more effectively by considering various factors that affect the outcome.

In evaluating solutions, participants showed a better understanding in assessing the effectiveness of the approaches they used. They were not only able to identify the strengths and weaknesses of the applied solution, but also to provide better improvement alternatives based on the analyses that had been conducted.

Overall, the results of this study indicate that the applied learning model is effective in improving participants' critical thinking, analytical and problem solving skills. Although it has shown positive results, there is still room for further improvement to ensure the effectiveness of this model can continue to grow and provide more optimal results in the future.

Recent studies have consistently demonstrated the effectiveness of PBL in improving students' problem-solving, critical thinking and conceptual understanding skills at different levels of education. PBL has been shown to improve science learning outcomes and foster independent learning habits [32], [33]. When implemented in higher education, PBL facilitates the development of important skills such as communication, collaboration, and information literacy [34]. The flexibility of this model allows for creative adaptation based on learner characteristics and available resources. Despite PBL's proven effectiveness, researchers identified gaps in understanding its integration with existing curricula and other learning methods [35]. Further investigation is needed to explore the impact of contextual factors, such as learning environment and teacher support, on the success of PBL. These findings suggest that PBL is not only a theoretical concept, but also a practical and effective approach in education.

Conclusions

Based on the results of descriptive data analysis, there are differences and improvements in students' problem solving skills after treatment. This is supported by the results of statistical tests that show a significant difference between the results before and after the treatment of the Internet of Things (IoT)-based Problem Based Learning model on improving students' problem solving skills. This finding is reinforced by the results of the gain analysis which shows that the increase that occurs is in the effective category. Thus, it can be concluded that the applied learning strategy or approach is able to make a positive contribution in improving students' ability to solve problems. The intervention proved to be successful and feasible to be applied as a learning model that supports the improvement of the quality of learning in the educational environment.

References

1) Alfianiawati, T., Desyandri, & Nasrul. (2019). Pengaruh penggunaan model problem based learning terhadap hasil belajar siswa dalam pembelajaran ISD di kelas V SD. Ejournal Pembelajaran Inovatif: Jurnal Ilmiah Pendidikan Dasar, 7(3), 1–10. https://doi.org/10.24036/e-jipsd.v7i3.5400
2) Ali, J., Madni, S. H. H., Jahangeer, M. S. I., & Danish, M. A. A. (2023). IoT adoption model for e-learning in higher education institutes: A case study in Saudi Arabia. Sustainability, 15(12), 9748. https://doi.org/10.3390/su15129748
3) Ananda, S., & Mulhamah, M. (2024). Penerapan pendekatan pembelajaran berbasis masalah dalam meningkatkan keterampilan pemecahan masalah siswa sekolah menengah. Jurnal Ulul Albab, 27(1), 1. https://doi.org/10.31764/jua.v27i1.23323
4) Asri, I. H., Jampel, I. N., Arnyana, I. B. P., Suastra, I. W., & Nitiasih, P. K. (2024). Profile of problem based learning (PBL) model in improving students' problem solving and critical thinking ability. KnE Social Sciences. https://doi.org/10.18502/kss.v9i2.14898
5) Cahaya, C., Mahmud, B., Darfin, S. A., Eka, N., & Munawir, R. (2024). Pengaruh pendidikan orang tua dan gender terhadap kemampuan berpikir kritis anak usia 5–6 tahun. Ihya Ulum Early Childhood Education Journal, 2, 295–311. https://doi.org/10.59638/ihyaulum.v2i2.269
6) Choi, J.-S., Bae, S.-M., Shin, S.-J., Shin, B.-M., & Lee, H.-J. (2022). Effects of problem-based learning on the problem-solving ability and self-efficacy of students majoring in dental hygiene. International Journal of Environmental Research and Public Health, 19(12), 7491. https://doi.org/10.3390/ijerph19127491
7) Creswell, J. W., & Creswell, J. D. (2018). Research design: Qualitative, quantitative, and mixed methods approaches (5th ed.). Sage Publications.
8) DeCaro, M. S., Isaacs, R. A., Bego, C. R., & Chastain, R. J. (2023). Bringing exploratory learning online: Problem-solving before instruction improves remote undergraduate physics learning. Frontiers in Education, 8. https://doi.org/10.3389/feduc.2023.1215975
9) Dunnett, K. (2022). Understanding the nature of students' experience of pre-university practical work in physics. European Journal of Physics, 43(5), 055707. https://doi.org/10.1088/1361-6404/ac7e88
10) Ernawati, M. D. W., Sudarmin, S., Asrial, A., Muhammad, D., & Haryanto, H. (2022). Creative thinking of chemistry and chemistry education students in biochemistry learning through problem based learning with scaffolding strategy. Jurnal Pendidikan IPA Indonesia, 11(2), 282–295. https://doi.org/10.15294/jpii.v11i2.33842
11) Ghashim, I. A., & Arshad, M. (2023). Internet of Things (IoT)-based teaching and learning: Modern trends and open challenges. Sustainability, 15(21), 15656. https://doi.org/10.3390/su152115656
12) Gumisirizah, N., Muwonge, C. M., & Nzabahimana, J. (2024). Effect of problem-based learning on students' problem-solving ability to learn physics. Physics Education, 59(1), 015015. https://doi.org/10.1088/1361-6552/ad0577
13) Hasmawaty, Usman, & Intisari. (2023). Improving children's science skills through play activities in outdoor play. Tematik: Jurnal Pemikiran dan Penelitian Pendidikan Anak Usia Dini, 9, 45–54. https://doi.org/10.26858/tematik.v9i1.47953
14) Hutasoit, S. A. (2021). Pembelajaran Teacher Centered Learning (TCL) dan Project Based Learning (PBL) dalam pengembangan kinerja ilmiah dan peninjauan karakter siswa. Jurnal Pendidikan Indonesia, 2(10), 1775–1799. https://doi.org/10.59141/japendi.v2i10.294
15) Irawati, F. I. M., & Sulisworo, D. (2023). Utilising smart water monitoring with IoT in science learning with problem-based learning model: Impact on critical thinking skills and the role of learning interest. Journal of Pedagogical Research. https://doi.org/10.33902/JPR.202323708

16) Ismail, H., & Edi. (2023). Student need analysis of problem-based learning model with blended learning in EFL academic reading. International Journal of English Language and Literature Studies, 12(1), 1–16. https://doi.org/10.55493/5019.v12i1.4698
17) Kanyesigye, S. T., Uwamahoro, J., & Kemeza, I. (2023). Effect of problem-based learning on Ugandan secondary school physics classroom practices: An observational study. F1000Research, 12, 245. https://doi.org/10.12688/f1000research.129221.1
18) Kusnandar, K., Harisudin, M., Riptanti, E. W., Khomah, I., Setyowati, N., & Qonita, R. A. (2023). Prioritizing IoT adoption strategies in millennial farming: An analytical network process approach. Open Agriculture, 8(1). https://doi.org/10.1515/opag-2022-0179
19) Low, K. C., Mohamad, S. S., Chong, S. L., Rahman, M. A. A., Purnomo, E. P., & Gunsuh, A. (2024). Improving university students' critical thinking and problem-solving skills: How problem-based learning works during COVID-19 pandemic? Journal of Advanced Research in Applied Sciences and Engineering Technology, 37(2), 165–176. https://doi.org/10.37934/araset.37.2.165176
20) Marcinauskas, L., Iljinas, A., Čyvienė, J., & Stankus, V. (2024). Problem-based learning versus traditional learning in physics education for engineering program students. Education Sciences, 14(2), 154. https://doi.org/10.3390/educsci14020154
21) Maries, A., & Singh, C. (2023). Helping students become proficient problem solvers part I: A brief review. Education Sciences, 13(2), 156. https://doi.org/10.3390/educsci13020156
22) Nicholus, G., Muwonge, C. M., & Joseph, N. (2023). The role of problem-based learning approach in teaching and learning physics: A systematic literature review. F1000Research, 12, 951. https://doi.org/10.12688/f1000research.136339.2
23) Novitra, F., Festiyed, F., Yohandri, Y., & Asrizal, A. (2021). Development of online-based inquiry learning model to improve 21st-century skills of physics students in senior high school. Eurasia Journal of Mathematics, Science and Technology Education, 17(9), em2004. https://doi.org/10.29333/ejmste/11152
24) Oktaviani, M. A., & Notobroto, H. B. (2014). Perbandingan tingkat konsistensi normalitas distribusi metode. Jurnal Biometrika dan Kependudukan, 3(2), 127–135. https://repository.unair.ac.id/124912/
25) Rachmawati, U., Pradita, L. E., Ulyan, M., & Sotlikova, R. (2024). The implementation of project-based learning in higher education: A case study in the Indonesian context. Journal of Languages and Language Teaching, 12(1), 475. https://doi.org/10.33394/jollt.v12i1.8976
26) Rodriguez-Sanchez, C., Orellana, R., Fernandez Barbosa, P. R., Borromeo, S., & Vaquero, J. (2024). Insights 4.0: Transformative learning in industrial engineering through problem-based learning and project-based learning. Computer Applications in Engineering Education, 32(4). https://doi.org/10.1002/cae.22736
27) Roig, P. J., Alcaraz, S., Gilly, K., Bernad, C., & Juiz, C. (2024). Design and assessment of an active learning-based seminar. Education Sciences, 14(4), 371. https://doi.org/10.3390/educsci14040371
28) Ruslan, R., Lu'mu, L., Fakhri, M. M., Ahmar, A. S., & Fadhilatunisa, D. (2024). Effectiveness of the flipped project-based learning model based on Moodle LMS to improve student communication and problem-solving skills in learning programming. Education Sciences, 14(9), 1021. https://doi.org/10.3390/educsci14091021
29) Sawilowsky, S. S., & Hillman, S. B. (1992). Power of the independent samples t test under a prevalent psychometric measure distribution. Journal of Consulting and Clinical Psychology, 60(2), 240–243. https://doi.org/10.1037/0022-006X.60.2.240
30) Sengul, O. (2024). Linking traditional teaching to innovative approaches: Student conceptions in kinematics. Education Sciences, 14(9), 973. https://doi.org/10.3390/educsci14090973
31) Sugiyono. (2018). Metode penelitian pendidikan: Pendekatan kuantitatif, kualitatif, dan R&D. Alfabeta.
32) Triani, E., Oktami, L., Inghug, D., & Rizqiyah, N. N. (2024). Unlocking cognitive potential: Enhancing problem-solving abilities through innovative problem-based learning models. EduFisika: Jurnal Pendidikan Fisika, 9(1), 54–62. https://doi.org/10.59052/edufisika.v9i1.32651
33) Usman, U., Zulhidayah, T., & Lestari, W. (2024). Kegiatan play outdoor untuk mengembangkan kemampuan motorik anak taman kanak-kanak usia 5–6 tahun. Murhum: Jurnal Pendidikan Anak Usia Dini, 5(1), 928–943. https://doi.org/10.37985/murhum.v5i1.452
34) Zeeshan, K., Hämäläinen, T., & Neittaanmäki, P. (2022). Internet of Things for sustainable smart education: An overview. Sustainability, 14(7), 4293. https://doi.org/10.3390/su14074293
35) Zhang, W., Lu, M., & Yang, P. (2023). An empirical study about the impact of project-based learning on reading literacy of primary students in a blended learning environment. Psychology in the Schools, 60(12), 4930–4945. https://doi.org/10.1002/pits.22949