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PAPER

Enhancing Learning Outcomes and Student Engagement: Integrating E-Learning Innovations into Problem-Based Higher Education

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ABSTRACT

With the rapid development of e-learning in higher education, this study explores the application of the problem-based learning (PBL) learning model in the e-learning ecosystem. This article explores the concept of participatory engagement in the e-learning ecosystem and integrates it with PBL theory through the use of ICT to support interaction and collaboration. The research method used is R&D learning models in the Heavy Equipment Technology course at Universitas Negeri Padang. The research findings should be interpreted cautiously due to limitations such as differences in contexts across various courses and factors related to technology implementation in the learning environment. The study results show that it can improve learning outcomes and students' critical thinking skills. Specifically, 70% have implemented Bloom's cognitive taxonomy Level C4 and above, aided by a self-reflection participation process that enables students to reflect on content, learning processes, and understanding through internal dialogue, generating new ideas and solutions. This is evidenced by the results of the Path Coefficients test with P-Value EE → LO 0.050 and PBL → LO 0.046, as well as Specific Indirect Effect EE → SPR → LO 0.003 and PBL → SPE → LO 0.047 where the value is ≤ 0.05. The implications include guidance for designing effective e-learning ecosystems and adaptive learning strategies in higher education. Future research is recommended to further explore the impact of this integration and develop more effective PBL models in diverse courses and other educational institutions.

KEYWORDS

e-learning, problem-based learning (PBL) learner engagement, learning outcomes, e-learning ecosystem, learner reflection

1 INTRODUCTION

The rapid growth in education has popularized e-learning as a key tool in higher education for productive and collaborative learning. It is replacing traditional

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teaching with online methods that offer flexibility and distance learning. This reliance on e-learning is attributed to advances in ICT, which provide enhanced opportunities for learner-educator interaction, online collaboration, and two-way communication [1], [2]. This research focuses on participatory engagement in the e-learning ecosystem, emphasizing the importance of collaboration and interaction among learners, educators, and learning materials to promote engagement and learning success [3]. The research explores the role of participatory learning theory in enhancing engagement in e-learning networks, with a specific focus on using ICT and learning materials to support learner engagement and participatory learning. The integration of the problem-based learning (PBL) model with the e-learning ecosystem is also discussed [4], [5]. The research involves a comprehensive search for primary studies and the development of conceptual models for participatory learning in the e-learning community. It emphasizes the importance of interaction, collaboration, and self-reflection in e-learning. Overall, the study has implications for learners, educators, and developers in designing effective e-learning ecosystems [6].

Problem-based learning enhances critical thinking and learning activities through technology, fostering positive interactions between learners and educators. While PBL shows promise in enhancing problem-solving, critical thinking, and communication skills, as well as fostering learning independence, inconsistent results warrant further research, particularly in the realm of e-learning [7–9]. Despite its advantages, PBL has drawbacks such as reduced emphasis on inquiry, challenges in formulating problems, and issues with time management and learner discipline [10–12]. However, disadvantages of PBL include orientation towards the less inquiry component, difficulty in formulating problems, less effective time management, a lack of learner initiation and discipline, and the need for more challenging authentic problems [13]. To address these concerns and enhance higher order thinking skills (HOTS) for the industrial revolution 4.0 era, future research should focus on refining the PBL model and assessing its validity, practicability, and effectiveness [14–16].

Online PBL offers self-learning, collaboration, and problem-solving benefits, although challenges such as smartphone use persist. Tara International School's studies reveal the effectiveness of PBL-Coach (cPbL), a virtual learning environment, in enhancing outcomes, with a focus on technological constraints [17–21]. Further research should assess cPbL across diverse contexts and subjects, integrating PBL principles into virtual learning environments [22–24]. Blended learning (BL), bPbL, combining online and face-to-face methods, aligns with cPbL in evaluation and learning time, providing flexibility in location and time savings. Research is advised to explore the impact of interactive online platforms on contextual and collaborative learning. In the United States, the integration of PBL and VR in engineering education enhances engagement, yet challenges related to high costs persist. Future research should span disciplines, extend into STEM fields, and employ more objective evaluation methods [25–27]. PBL with VR enhances learner engagement and understanding, but challenges such as high costs and integration issues exist. Future research should encompass diverse disciplines, extend into STEM fields, and prioritize more objective evaluation methods [28–30].

Problem-based learning in online learning involves several steps, such as presenting problems, self-directed or group analysis, online discussions, solution development, and presentations. At SMA Negeri Plus Riau, class XI utilizes PBL with the BL method for teaching excretory system material, providing flexibility and promoting independent learning [22], [31], [32]. Despite enhancing critical and creative thinking, limitations include a lack of evaluation skills and limited generalization. Future research should involve more schools, classrooms, and variables such as learning motivation and parental participation [33–35].

In Computer and Information Technology 1 (CIT1), PBL on Facebook enhances problem-solving and programming skills but faces challenges in accessibility and learners' technological skills [5]. Research in Indonesian high schools show the advantages of PBL in improving learning outcomes and spatial thinking. However, it also highlights challenges related to interaction in fully online settings. Recommendations include expanding to higher education and integrating PBL with blended learning [36–38]. At the Biology Education Study Program at the University of Bengkulu, PBL with BL enhances learning engagement and fosters critical thinking skills. Challenges include internet access and technology understanding, with recommendations for broader learner and subject inclusion and consideration of interactive online platforms [39–42]. PBL principles in online learning involve cognitive development, material transformation, and evaluation of benefits and drawbacks. Advantages include task authenticity, independent learning, and varied teaching methods. Drawbacks include the difficulty of finding suitable solutions and materials. Research suggestions include exploring technology support for PBL and engaging teaching strategies in online learning, especially PBL [43–46].

Research at SMA Islam As-Shofa in Pekanbaru, underscores the effectiveness of (PBL) in improving higher-order thinking skills and academic achievements among 12th-grade science students using online platforms such as Zoom, Google Meet, and Google Classroom [47–50]. Abai Kazakh National Pedagogical University's study in Kazakhstan reveals that the e-learning environment supports PBL by providing diverse resources and fostering interaction between learners and teachers, thereby increasing engagement and collaboration [51–54]. However, limitations include restricted social interaction and experiences because of a unified online platform. Strategies such as optimizing face-to-face learning based on the e-learning ecosystem are recommended [55–57]. At the Faculty of Information and Communication Technology, Mataram Universityof Technology, e-PBL research demonstrates benefits in terms of time and space flexibility, student collaboration, and enhanced information system analysis skills. Challenges involve technical aspects and training support. Recommendations focus on developing sophisticated e-PBL applications, incorporating more disciplines, and exploring interactive online platforms and advanced technology to enhance the effectiveness of PBL with blended learning methods [58–61].

It is important to address identified deficiencies by offering a more balanced discussion that emphasizes potential obstacles and criticisms associated with integrating PBL into the e-learning ecosystem. This will help improve the overall quality and depth of the research. This method would provide readers with a more nuanced view by addressing topics such as learner discipline, uneven technology accessibility, and potential PBL model flaws. Furthermore, a more thorough examination of the pedagogical changes required for PBL to be successfully implemented in online learning is essential. These changes should include aspects such as curriculum design, assessment techniques, and teacher preparedness. By focusing on these areas, the study can offer insightful information on the practical considerations and modifications that educators and institutions need to make to successfully implement PBL in an online learning environment. A more coherent synthesis of the most important data is now required, despite the insightful information from several research studies on PBL integration. Finding overarching themes and patterns in the current dispersion of knowledge across various educational contexts, technologies, and issues can be challenging for readers. The synthesis should focus on identifying similarities, differences, and emerging trends in the impact of PBL in the context of e-learning to enhance accessibility and clarity. This comprehensive summary will make a significant contribution to the existing body of knowledge and aid educators, researchers, and policymakers in navigating the rapidly evolving field of e-learning and interactive learning approaches [62], [63].

Researchers are intrigued by the possibility of elaborating on the research results mentioned above. They are interested in innovating by integrating the e-learning ecosystem into the PBL learning model. This research focuses on participatory learning in within the e-learning ecosystem, which includes structured and independent learning activities conducted online as well as face-to-face activities offline. This model maximizes the function of e-learning as a complement. This learning model emphasizes the significance of interaction, collaboration, and reflection, and it has implications for learners, educators, and developers when designing effective e-learning ecosystems. This study aims to investigate the impact of integrating PBL learning models with the e-learning ecosystem on learners' participation and learning outcomes.

2 RESEARCH METHODS

This article aims to provide a comprehensive overview of the conceptual framework that underlies our research in exploring the potential integration of e-learning ecosystems in PBL within higher education institutions. This conceptual framework outlines the theoretical foundations, key variables, and relationships between variables that are the focus of the analysis. By exploring the core elements of problem-based learning and integrating innovative aspects of the e-learning ecosystem, this conceptual framework is expected to provide a strong foundation for a comprehensive understanding of the positive impact that this approach can have on student learning outcomes. By detailing the structure and interrelationships of key variables, we hope that this conceptual framework will provide valuable guidance for future research and contribute to the development of more adaptive and responsive learning strategies at the higher education level.

The research method used is the research and development (R&D) learning model. The instruments used to collect the data include test sheets, questionnaires, and observations [1]. This study involved 50 students who were enrolled in Heavy Equipment Technology courses in the S-1 Automotive Engineering Education Study Program at Padang State University, Indonesia. The three-month research period, spanning from August 2023 to October 2023, included eighteen meetings. The range of values that appear is also utilized to calculate data from observations of learning activities and set the criteria. The indications of critical thinking ability—such as problem formulation, argumentation, deduction, induction, evaluation, and decision-making—are utilized to analyze students' critical thinking skills. After calculating the overall score for each indicator, the percentage is determined.

This study utilizes reflective measurement models for the concepts of "Improvement of Learning Outcome" and "Student Participation" ensuring internal consistency of selected indicators. Confirmatory factor analysis is used to assess the degree to which indicators reflect latent constructs. The reflective model provides flexibility to changes in indicators, is relevant for measuring progress over time in the e-learning environment, and is expected to improve the accuracy of research results related to the innovative integration of the e-learning ecosystem PBL in higher education [6].

This study utilizes SmartPLS 4 for data analysis to enhance critical thinking skills in the context of heavy equipment technology learning. The partial least squares structural equation modeling (PLS-SEM) method is utilized, which includes assessing measurement and structural models as well as evaluating the goodness of fit of the models. SmartPLS 4 outputs, including standard values such as average variance extracted (AVE), coefficient of determination (R2), and path coefficient significance, will be interpreted. The evaluation also includes the use of specific indirect effect (SIE) to identify the role of mediators in variable relationships [64].

The variables used in this study by researchers are in the form of independent variables, including ecosystem e-learning (X1) and PBL (X2). Intervening variables include student participation with content (Z1), student participation with students (Z2), student participation with educators (Z3), student participation with self-reflection (Z4), and the dependent variable learning outcomes (Y). The aforementioned variables will be measured and evaluated based on the distribution of questionnaires for variables X1, X2, Z1, Z2, Z3, and Z4. However, for Y, it will be derived from data on student achievements during lectures. For more details about variable measurements, researchers will show them in Table 1.

Table 1. Research variables

Variable	Measurement Items	Indicator
Ecosystem E-Learning (EE)	X1.1	YouTube Media Original Material Researchers
	X1.2	Display/Interface Konten E-learning
	X1.3	Content Accessibility
	X1.4	Content Module
Problem-Based Learning (PBL)	X2.1	Discussion Between People
	X2.2	Best Solutions produced
	X2.3	Solution Presentation
	X2.4	Each group's response
Student Participation with Content (SPC)	Z1.1	Measure the extent to which students are actively engaged with the learning material presented
	Z1.2	The level of student exploration of learning content and their activeness in seeking additional information
	Z1.3	How often students interact with learning material, such as composing questions, giving responses, or discussing content
Student Participation with Students (SPS)	Z2.1	The level of collaboration and interaction between students and others in learning activities
	Z2.2	The extent of student involvement in group discussions or cooperative activities with peers
	Z2.3	Measure how students give and receive feedback from others during the learning process
Student Participation with Educators (SPE)	Z3.1	How often students interact with educators, including questions, discussions, or consultations
	Z3.2	The extent to which students receive feedback and guidance from their educators
	Z3.3	Measure whether students seek academic support and participate in resources provided by educators
Student Participation with Self-Reflection (SPR)	Z4.1	How often students engage in self-reflection activities, such as personal evaluations
	Z4.2	The extent to which students set personal goals and involve themselves in the self-planning process
	Z4.3	Measure whether students are actively self-assessing their progress in learning
Learning Outcomes (LO)	Y1.1	Students' academic performance following participation in problem-based learning with the e-learning ecosystem integrated
	Y1.2	The degree to which students' involvement in problem-based learning helps them enhance their problem-solving abilities
	Y1.3	Critical thinking abilities of students as a result of problem-based learning, particularly through experiential learning
	Y1.4	Assess the degree to which students can utilise the knowledge they have acquired in practical or real-world settings.

The conceptual structure of this study will be further explained in Figure 1 for additional information. In this regard, integrating the e-learning environment is starting to show promise as a way to improve student learning outcomes and enhance learning effectiveness.

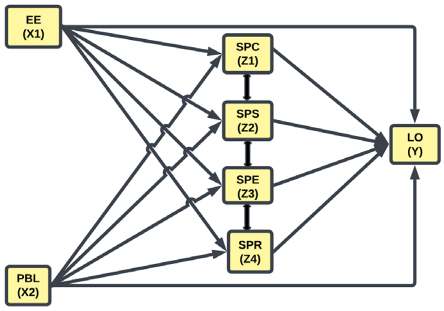

Fig. 1. Research conceptual framework

3 RESULTS AND DISCUSSION

Partial least squares structural equation modeling analysis has become a popular research method in education for examining relationships between variables in conceptual models. In this study, we utilized SmartPLS4 to conduct PLS-SEM analysis to gain a deeper understanding of the relationship between variables. As a result, we present graphs illustrating the validation of the model and the degree to which the constructs involved demonstrate a significant relationship in this study. The following researchers present the results of the PLS-SEM output in Figure 2.

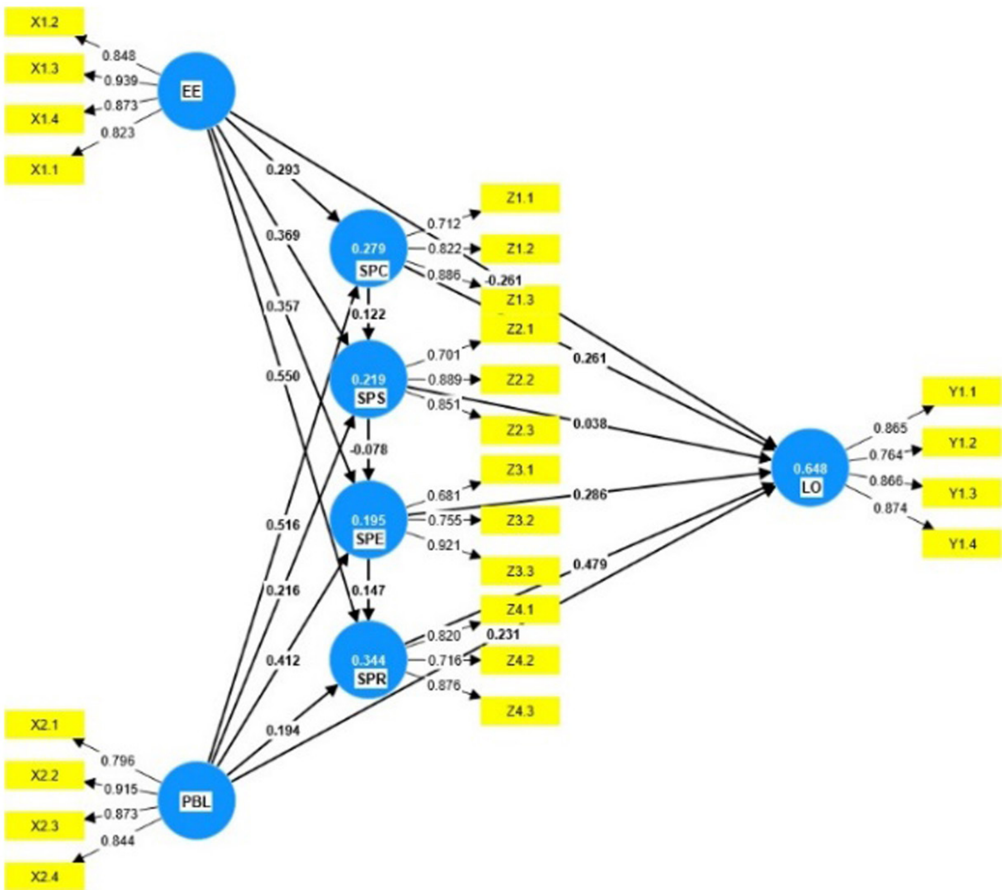

Fig. 2. PLS-SEM output results

3.1 Measurement model evaluation

The results of the convergent validity calculation for each variable are presented in Table 2.

Table 2. Convergent validity

Variable	Cronbach's Alpha	Composite Reliability (rho_a)	Composite Reliability (rho_c)	Average Variance Extracted (AVE)
EE	0.897	0.983	0.927	0.760
LO	0.864	0.880	0.908	0.711
PBL	0.886	0.942	0.918	0.736
SPC	0.763	0.895	0.850	0.656
SPE	0.765	1.159	0.832	0.627
SPR	0.746	0.823	0.848	0.651
SPS	0.759	0.814	0.857	0.669

Convergent validity analysis revealed favorable outcomes for the study's measurement tools. With values over 0.70, all Cronbach's Alpha values for the constructs of EE, LO, PBL, SPC, SPE, SPR, and SPS are at a good level, indicating excellent instrument reliability. Furthermore, the composite reliability values (rho_a and rho_c) exhibit high values, indicating consistency among the items comprising the construct. This increases trust in the dependability of the measurement device. Additionally, each construct's AVE values are above 0.50, suggesting that they can account for the majority of their own variability. These numbers are also quite impressive. This is based on the terms of reference [64]. Based on these results, it can be said that the measurement tools used in this study are valid and reliable for measuring the variables EE, LO, PBL, SPC, SPE, SPR, and SPS since they demonstrate a high degree of dependability and excellent convergence with the concept being measured. The results of the discriminant validity calculation for each variable are presented in Table 3.

Table 3. Discriminant validity

	EE	LO	PBL	SPC	SPE	SPR	SPS
EE	1.000						
LO	0.219	1.000					
PBL	0.151	0.586	1.000				
SPC	0.307	0.521	0.459	1.000			
SPE	0.233	0.487	0.398	0.278	1.000		
SPR	0.586	0.644	0.283	0.336	0.330	1.000	
SPS	0.456	0.393	0.331	0.403	0.155	0.667	1.000

Based on the results of the correlation matrix analysis, it can be concluded that the conceptual model of this study has successfully achieved an acceptable level of discriminant validity between the constructs involved, as all correlation coefficients obtained are below 0.90. Correlations between construct variables, such as EE, LO, and PBL, tend to remain at distinguishable levels, suggesting that each construct is conceptually distinct from the others. The weak correlation values between EE and LO, as well as PBL and LO, support the belief that these concepts have unique properties and are not closely related within the framework of this study. Similarly, the low correlation between learner-participation variables (SPC, SPE, SPR, SPS) suggests that each of these variables is distinct, providing a solid foundation for examining their impact on LO.

In conclusion, these findings provide empirical support for the construct validity in research models, confirming that measurement instruments are reliable for measuring the concepts being studied. This information provides a solid foundation for further interpretation of the results and findings within the study's context.

3.2 Structural model evaluation

The fundamental components of PLS-SEM analysis are structural models, which enable us to comprehend the relationships between variables within the study framework. Evaluation becomes a crucial stage in ensuring the validity and dependability of research findings when considering the quality of structural models. To complete this assessment, several important details are provided, including the strength of the association, the analysis of the variance, and the significance test for the parameters. Through the implementation of a comprehensive assessment of structural models, this investigation can ensure the validity of results and provide a detailed perspective on the dynamics of variable connections within the research framework. The evaluation's findings serve as a strong foundation for a more comprehensive explanation of the significance and implications of the study findings. The findings of the structural model examination are presented below.

The mentioned variance analysis (R-squared) gives a sense of how well the dependent variable's variation can be explained by the model. When the R-squared number is high, the model is doing a good job of explaining the data's variability. The R-squared test results are displayed in Table 4.

Table 4. Coefficient of determination

	R-Square	R-Square Adjusted
LO	0.648	0.598
SPC	0.279	0.248
SPE	0.195	0.143
SPR	0.344	0.301
SPS	0.219	0.168

The table's R-squared and adjusted R-squared analyses demonstrate how effectively structural models can explain changes in the dependent variable. With an R-squared of almost 64.8%, the variable LO indicates that the independent factors in the model account for the majority of the variation in learning outcomes attainment. This percentage remained constant at 59.8% after adjustment. The independent variable may account for approximately 27.9% of the variation in learner involvement with content, as indicated by the SPC variable's R-squared of about 27.9%, which decreased to 24.8% after adjustment. Lower R-squared values for the SPE and SPS variables suggest that the variances in learners' interactions with teachers and peers may not have been fully accounted for by the model.

After correction, the R-squared for the SPR variable dropped to 30.1%, indicating that the independent variable could account for approximately 34.4% of the variation in learner involvement with self-reflection. In general, the model exhibits a high level of confidence in its capacity to elucidate fluctuations in dependent variables. The strong R-squared and adjusted R-squared values of the LO variable demonstrate the quality and reliability of the model in capturing how specific circumstances affect learning outcomes. This review sheds light on how well the model explains differences in learner engagement concerning content, teachers, self-reflection, and other learners, despite the learner participation variable having a lower R-squared value. To sum up, the model provides a solid framework for examining the correlations between variables. However, further interpretation should consider the theoretical background and real-world applications of these results.

This section contains graphical data that illustrates the extent to which the constructs examined in this study are meaningfully linked and provides a visual summary of the validation of path coefficient relevance and statistical significance. By carrying out a bootstrapping test, the researcher presents the results graphically in Figure 3.

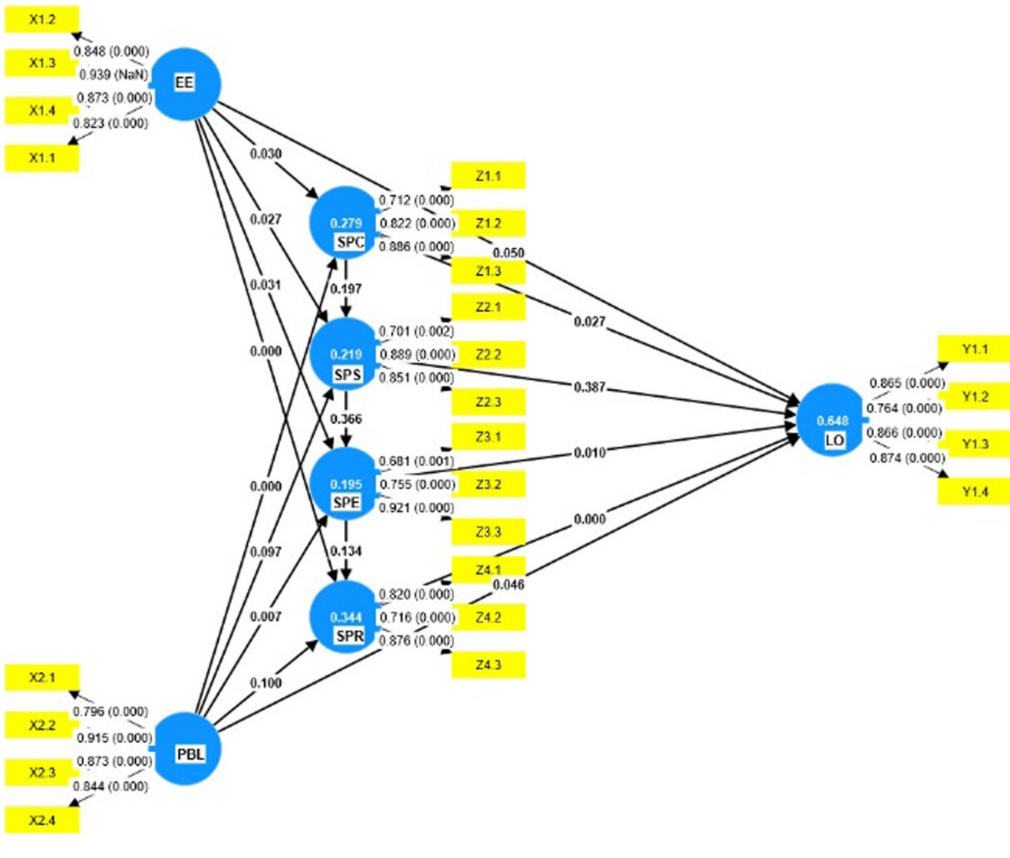

Fig. 3. Bootstrapping output graphic

The route and loading coefficients are used to quantify the strength of the relationship between the variables. An indication of a strong correlation between the independent and dependent variables is a significant path coefficient. The indications thus demonstrate a strong reflection of the measured construct, as evidenced by a high factor loading on the latent variable. The output will be displayed in Table 5.

Table 5. Statistical significance and relevance of path coefficients

Research Hypothesis		Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	P Values	Result
H1	EE → LO	–0.261	–0.244	0.159	1.647	0.050	Accepted
H2	EE → SPC	0.293	0.293	0.155	1.884	0.030	Accepted
H3	EE → SPE	0.357	0.379	0.192	1.864	0.031	Accepted
H4	EE → SPR	0.550	0.540	0.165	3.334	0.000	Accepted
H5	EE → SPS	0.369	0.369	0.192	1.924	0.027	Accepted
H6	PBL → LO	0.231	0.231	0.137	1.686	0.046	Accepted
H7	PBL → SPC	0.516	0.527	0.109	4.715	0.000	Accepted
H8	PBL → SPE	0.412	0.415	0.169	2.435	0.007	Accepted
H9	PBL → SPR	0.194	0.196	0.152	1.279	0.100	Rejected
H10	PBL → SPS	0.216	0.216	0.167	1.297	0.097	Rejected
H11	SPC → LO	0.261	0.249	0.135	1.925	0.027	Accepted
H12	SPC → SPS	0.122	0.121	0.143	0.853	0.197	Rejected
H13	SPE → LO	0.286	0.290	0.123	2.324	0.010	Accepted
H14	SPE → SPR	0.147	0.157	0.133	1.107	0.134	Rejected
H15	SPR → LO	0.479	0.472	0.136	3.536	0.000	Accepted
H16	SPS → LO	0.038	0.037	0.132	0.286	0.387	Rejected
H17	SPS → SPE	–0.078	–0.051	0.228	0.343	0.366	Rejected

Analysis of statistical significance and relevance of path coefficients revealed several important findings. The relationship between EE and LO was negative (coefficient –0.261), significant at a 95% confidence level (T statistics: 1.647, P value: 0.050). EE has a significant positive relationship with SPC (coefficient 0.293) and SPE (coefficient 0.357), as well as a highly significant relationship with SPR (coefficient 0.550) and SPS (coefficient 0.369). PBL also makes a significant positive contribution to LO (coefficient 0.231), SPC (coefficient 0.516), SPE (coefficient 0.412), and SPR (coefficient 0.194). Although PBL's association with SPS and some other relationships showed positive correlations, not all reached conventional levels of significance. Thus, the results of the analysis provide insight into the strength and significance of various relationships within the structural model being studied.

Analysis of path coefficients reveals key findings concerning variable relationships in structural models. EE has a significant negative relationship with LO, while it has a significant positive relationship with learner participation (SPC, SPE, SPR, SPS). This is in accordance with research indicating that PBL makes a significant positive contribution to LO and SPC, as well as SPE and SPR. Although the association of learner participation with LO is not necessarily significant at the 95% level, the findings suggest a potential positive impact of learner participation on learning outcomes. These conclusions offer deeper insights into the intricate interactions among EE, PBL, learner participation, and LO. This is beneficial for policymakers and education practitioners when designing more effective strategies in PBL models.

This result is consistent with other studies demonstrating a strong relationship between PBL utilization and the e-learning ecosystem within the realm of modern education. PBL may be successfully used in the e-learning ecosystem to support students' cognitive growth and cooperative learning [43]. Students can interact with instructors, other students, and real-world web content in e-learning environments [1]. In addition, the e-learning ecosystem can be utilized as a tool in conjunction with the integration of PBL in classroom instruction to foster interaction among students and facilitate the exploration of challenging concepts, aligning with the collaborative essence of e-learning. Therefore, integrating PBL into the e-learning ecosystem can enhance the effectiveness of online education by fostering active learning, problem-solving skills, and cognitive development. It can also improve the effectiveness of online education and BL among learners.

3.3 Model match

When assessing the indirect influence of an individual mediator on the dependent variable (DV), researchers employ the specific indirect effect (SIE) in pathway analysis. SIE explains the role of each mediator in the interaction between IV and DV and assists in identifying specific pathways that have a significant influence in a model. SIE analysis helps create theories, refines conceptual models, provides a comprehensive understanding of the mechanics underlying variable interactions, and offers a breakdown of the contributions made by each component of the model. The findings of the specific indirect effect are displayed in Table 6.

Table 6. Specific indirect effect

Variable	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	P Values
PBL → SPC → SPS → SPE → SPR → LO	–0.000	–0.000	0.003	0.121	0.452
SPC → SPS → SPE → SPR	–0.001	–0.001	0.011	0.133	0.447
SPC → SPS → SPE → SPR → LO	–0.001	–0.001	0.005	0.125	0.450
EE → SPC → SPS → SPE	–0.003	–0.002	0.014	0.198	0.421
EE → SPS → SPE → SPR	–0.004	–0.003	0.020	0.209	0.417
PBL → SPC → SPS → SPE → SPR	–0.001	–0.001	0.006	0.128	0.449
PBL → SPE → SPR → LO	0.029	0.029	0.031	0.934	0.175
SPC → SPS → LO	0.005	0.006	0.027	0.171	0.432
EE → SPE → SPR	0.052	0.058	0.064	0.816	0.207
EE → SPR → LO	0.263	0.250	0.096	2.734	0.003
PBL → SPS → LO	0.008	0.013	0.037	0.221	0.412
EE → SPC → LO	0.076	0.071	0.057	1.332	0.092
PBL → SPC → SPS → SPE	–0.005	–0.004	0.023	0.217	0.414
SPS → SPE → SPR	–0.011	–0.005	0.048	0.240	0.405
PBL → SPS → SPE → SPR → LO	–0.001	–0.001	0.007	0.173	0.431
PBL → SPC → SPS	0.063	0.062	0.078	0.802	0.211

(Continued)

Table 6. Specific indirect effect *(Continued)*

Variable	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	P Values
PBL → SPC → SPS → SPE → LO	–0.001	–0.001	0.007	0.195	0.423
EE → SPS → SPE → SPR → LO	–0.002	–0.001	0.010	0.195	0.423
PBL → SPS → SPE	–0.017	–0.015	0.066	0.256	0.399
PBL → SPC → LO	0.134	0.133	0.084	1.602	0.055
EE → SPS → SPE	–0.029	–0.025	0.095	0.303	0.381
EE → SPC → SPS → SPE → LO	–0.001	–0.001	0.004	0.183	0.428
EE → SPS → LO	0.014	0.006	0.053	0.262	0.397
EE → SPS → SPE → LO	–0.008	–0.007	0.029	0.281	0.389
PBL → SPC → SPS → LO	0.002	0.003	0.014	0.169	0.433
EE → SPC → SPS → SPE → SPR → LO	–0.000	–0.000	0.002	0.113	0.455
PBL → SPE → SPR	0.061	0.060	0.063	0.958	0.169
PBL → SPE → LO	0.118	0.117	0.070	1.672	0.047
SPC → SPS → SPE	–0.010	–0.008	0.043	0.222	0.412
SPS → SPE → LO	–0.022	–0.013	0.070	0.322	0.374
EE → SPE → SPR → LO	0.025	0.028	0.034	0.747	0.228
EE → SPE → LO	0.102	0.109	0.077	1.324	0.093
SPC → SPS → SPE → LO	–0.003	–0.002	0.013	0.206	0.418
EE → SPC → SPS	0.036	0.033	0.051	0.696	0.243
EE → SPC → SPS → SPE → SPR	–0.000	–0.000	0.003	0.121	0.452
SPS → SPE → SPR → LO	–0.005	–0.003	0.025	0.222	0.412
PBL → SPR → LO	0.093	0.092	0.080	1.169	0.121
PBL → SPS → SPE → SPR	–0.002	–0.002	0.013	0.191	0.424
PBL → SPS → SPE → LO	–0.005	–0.004	0.021	0.233	0.408
SPE → SPR → LO	0.070	0.077	0.070	0.998	0.159
EE → SPC → SPS → LO	0.001	0.002	0.009	0.153	0.439

Based on the results of the SIE analysis, the main findings indicate that there is no significant special effect of PBL, SPC, or EE variables on the LO through the specific pathways specified in the SIE output. However, there are some interesting findings. First, there are significant special effects from EE to LO through the EE → SPR → LO pathway, indicating that the e-learning ecosystem has a substantial impact on learning outcomes through student participation with educators (SPR). Furthermore, PBL also demonstrates a significant influence on LO through the PBL → SPE → LO pathways, highlighting the significant role of student participation with educators (SPE) as mediators between problem-based learning and learning outcomes. Although some minor relationships with special effects were identified, such as EE → LO through multiple mediators, PBL → LO through multiple mediators, and EE → student participation with students (SPS) → LO.

This result is consistent with other studies that have found a strong correlation between learners' interactions for learning progress and their ability to address significant issues, which is closely linked to self-reflection within the e-learning environment. Through internal discussion, the reflection process enables students to consider the material, the learning process, and their comprehension, leading to the generation of new concepts and solutions based on prior experiences. They offer information from various perspectives in learning activities, enabling critical analysis and the integration of knowledge to create something new [65]. Additionally, self-reflection cultivates new resources, promotes higher-order thinking, and enhances the learning community. Therefore, self-reflection is essential for enhancing the e-learning ecosystem experience for students, enabling deeper contributions to the learning community and active participation [1]. PBL also helps students become more independent, provides a realistic view of academic obstacles, boosts their confidence, and enhances their problem-solving, critical thinking, and communication abilities [14], [15].

An in-depth examination of problem-based questions that align with cognitive level C4 of bloom's taxonomy has a significant impact on students' development of critical thinking abilities. Incorporating these types of questions into the classroom fosters higher-order cognitive abilities that go beyond simple memory or understanding. By using questions from cognitive level C4, students are forced to think analytically critically analyze, and evaluate the material. The previously described PBL approach is essential for fostering cognitive development. PBL challenges students to apply their knowledge, analyze complex problems, and generate solutions by immersing them in real-world scenarios. This supports the goals of cognitive level C4, by encouraging students to evaluate the significance of information, think critically, and draw defensible conclusions. The study emphasizes the value of utilizing problem-based questions at cognitive level C4 in the PBL framework and highlights how they help students in higher education develop and improve their critical thinking abilities [66].

Emphasizing cognitive level C4 and above questions within the PBL model not only enhances individual skill development but also fosters collaborative learning experiences. As students grapple with real-world problems, engaging in discussions and sharing perspectives, the collaborative aspect of PBL elevates the critical thinking process. This integration aligns with the broader goal of preparing students for the demands of the 21st-century workforce, where critical thinking skills are increasingly vital. The research advocates for intentionally incorporating cognitive level C4 and above questions within the PBL pedagogy, emphasizing their role in both academic development and equipping students with essential skills for future careers. The symbiotic relationship between cognitive level C4 and above questions and the PBL model emerges as a key theme in fostering critical thinking skills among higher education students. This approach not only enhances individual cognitive abilities but also promotes collaborative learning, preparing students for the challenges of the modern world. As educators and institutions refine pedagogical strategies, the intentional use of cognitive level C4 and above questions within the PBL framework emerges as a promising avenue for cultivating the next generation of critical thinkers and problem solvers.

4 CONCLUSION

The integration of PBL and e-learning ecosystems in modern education can effectively enhance cognitive development and promote collaborative learning among students. The e-learning ecosystem provides opportunities for interaction among learners, educators, and authentic online materials. The use of the e-learning ecosystem as a tool and the integration of PBL in classroom teaching can stimulate learner interaction and exploration of difficult concepts, aligning with the collaborative nature of e-learning. The integration of PBL into the e-learning ecosystem can enhance the effectiveness of online education by fostering active learning, problem-solving skills, and cognitive development. This integration can also improve the effectiveness of online education and BL among students. In addition, these findings show that self-reflection in the e-learning ecosystem plays an important role in learners' interactions, contributing to learning progress and problem-solving. The reflection process enables learners to contemplate the content and learning process, fostering the generation of new ideas based on past experiences. In the context of learning activities, self-reflection promotes higher-order thinking, generates new insights, and enriches the learning community. While PBL provides advantages in improving problem-solving skills, critical thinking, communication, and learning independence.

This combination provides a realistic picture of academic challenges, increases learner confidence, and enriches the learner experience in the e-learning ecosystem. Therefore, the integration of PBL and self-reflection can significantly enhance the quality and impact of learning within the e-learning ecosystem. It is important to emphasize that a more thorough understanding of the contextual and structural models is also required for a deeper understanding of the dynamics integrating of the e-learning ecosystem with problem-based learning.

4.1 Implications and suggestions

Further research is expected to develop a more innovative learning model to enhance participation (SPS). In this study, there was still a lack of significance of the SPS variable compared to several other variables. Consequently, further research across diverse courses and educational institutions is necessary to enhance our understanding of the broader implications of this integration.

To optimize the effectiveness of this learning model, it is important to prioritize and improve internet infrastructure. A reliable and high-speed internet network will ensure a smooth learning experience, supporting PBL integration within the e-learning ecosystem. These improvements not only facilitate a smoother learning process but also pave the way for continued progress in the e-learning ecosystem. Investing in robust internet connectivity is crucial for unleashing the full potential of this integrated education model.

5 REFERENCES

[1] H. Haron, N. H. Natrah Aziz, and A. Harun, "A conceptual model participatory engagement within e-learning community," *Procedia Computer Science*, vol. 116, pp. 242–250, 2017. https://doi.org/10.1016/j.procs.2017.10.046

[2] S.-S. M. Ajibade and A. Zaidi, "Technological acceptance model for social media networking in e-learning in higher educational institutes," *IJIET*, vol. 13, no. 2, pp. 239–246, 2023. https://doi.org/10.18178/ijiet.2023.13.2.1801

[3] W. Wagino, H. Maksum, W. Purwanto, K. Krismadinata, S. Suhendar, and R. D. Koto, "Exploring the full potential of collaborative learning and e-learning environments in Universities: A systematic review," *TEM Journal*, vol. 12, no. 3, pp. 1772–1785, 2023. https://doi.org/10.18421/TEM123-60

[4] Y. Yennita and A. Y. Zukmadini, "Problem-Based Learning (PBL) and blended learning in improving critical thinking skills and student learning activities in biochemistry courses," *J. Phys.: Conf. Ser.*, vol. 1731, p. 012007, 2021. https://doi.org/10.1088/1742-6596/1731/1/012007

[5] I. Alshaye, Z. Tasir, and N. F. Jumaat, "The conceptual framework of online problem-based learning towards problem-solving ability and programming skills," in *2019 IEEE Conference on e-Learning, e-Management & e-Services (IC3e)*, Pulau Pinang, Malaysia, 2019, pp. 1–4. https://doi.org/10.1109/IC3e47558.2019.8971780

[6] J. F. Hair, G. T. M. Hult, C. M. Ringle, M. Sarstedt, N. P. Danks, and S. Ray, "Evaluation of reflective measurement models," *Partial Least Squares Structural Equation Modeling (PLS-SEM) Using R: A Workbook*, pp. 75–90, 2021. https://doi.org/10.1007/978-3-030-80519-7_4

[7] H. Al-shehri *et al.*, "Assessment of the implementation of problem based learning model in Saudi medical colleges: A cross-sectional study," *Adv Med Educ Pract*, vol. 9, pp. 649–655, 2018. https://doi.org/10.2147/AMEP.S167290

[8] D. Desnita, F. Festiyed, F. Novitra, A. Ardiva, and M. Yussavel Navis, "The effectiveness of CTL-based Physics E-module on the improvement of the creative and critical thinking skills of senior high school students," *TEM Journal*, vol. 11, no. 2, pp. 802–810, 2022. https://doi.org/10.18421/TEM112-38

[9] M. H. Amiruddin, S. Sumarwati, and K. Amat, "The impact of problem-based learning (PBL) on student achievement in engineering subject material at vocational college Kuantan, Pahang," in *Online Journal for TVET Practitioners*, vol. 1, no. 1, pp. 1–6, 2021. https://doi.org/10.30880/ojtp.2021.06.01.001

[10] R. Tania, Jumadi, and D. P. Astuti, "The application of Physics e-handout assisted by PBL model use Edmodo to improve critical thinking skills and ICT literacy of high school students," *J. Phys.: Conf. Ser.*, vol. 1440, no. 1, p. 012037, 2020. https://doi.org/10.1088/1742-6596/1440/1/012037

[11] F. M. F. Wong and C. W. Y. Kan, "Online problem-based learning intervention on self-directed learning and problem-solving through group work: A waitlist controlled trial," *IJERPH*, vol. 19, no. 2, p. 720, 2022. https://doi.org/10.3390/ijerph19020720

[12] S. Wyke, A. A. Jensen, L. Krogh, O. Ravn, and K. Svidt, "Employability competences through short-term intensive PBL-events in higher education," *Front. Educ.*, vol. 7, p. 959355, 2022. https://doi.org/10.3389/feduc.2022.959355

[13] P. Yaniawati, D. Fisher, Y. D. Permadi, and S. A. M. Yatim, "Development of mobile-based digital learning materials in blended learning oriented to students' Mathematical literacy," *International Journal of Information and Education Technology (IJIET)*, vol. 13, no. 9, pp. 1338–1347, 2023. https://doi.org/10.18178/ijiet.2023.13.9.1936

[14] A. Aslan, "Problem-based learning in live online classes: Learning achievement, problem-solving skill, communication skill, and interaction," *Computers & Education*, vol. 171, p. 104237, 2021. https://doi.org/10.1016/j.compedu.2021.104237

[15] Y. Liu and A. Pásztor, "Effects of problem-based learning instructional intervention on critical thinking in higher education: A meta-analysis," *Thinking Skills and Creativity*, vol. 45, p. 101069, 2022. https://doi.org/10.1016/j.tsc.2022.101069

[16] B. K. Prahani *et al.*, "Blended Web Mobile Learning (BWML) model to improve students' higher order thinking skills," *Int. J. Emerg. Technol. Learn. (iJET)*, vol. 15, no. 11, pp. 42–55, 2020. https://doi.org/10.3991/ijet.v15i11.12853

[17] Y. P. Sari, Sunaryo, V. Serevina, and I. M. Astra, "Developing E-module for fluids based on Problem-Based Learning (PBL) for senior high school students," *J. Phys.: Conf. Ser.*, vol. 1185, p. 012052, 2019. https://doi.org/10.1088/1742-6596/1185/1/012052

[18] Sudarwanto, V. Serevina, D. A. Nugroho, and H. F. Lipikuni, "Development of online learning resource for accelerated linear motion material with the Problem Based Learning (PBL) model during the COVID-19 pandemic," *J. Phys.: Conf. Ser.*, vol. 2019, p. 012049, 2021. https://doi.org/10.1088/1742-6596/2019/1/012049

[19] Suharno, N. A. Pambudi, and B. Harjanto, "Vocational education in Indonesia: History, development, opportunities, and challenges," *Children and Youth Services Review*, vol. 115, p. 105092, 2020. https://doi.org/10.1016/j.childyouth.2020.105092

[20] R. Sujanem and I. N. Putu Suwindra, "Problem-based interactive Physics E-module in Physics learning through blended PBL to enhance students' critical thinking skills," *Jurnal Pendidikan IPA Indonesia (JPII)*, vol. 12, no. 1, pp. 135–145, 2023. https://doi.org/10.15294/jpii.v12i1.39971

[21] W. Sutopo and E. F. Aqidawati, "Learning a supply chain management course by problem based learning: Case studies in the newspaper industry," 2019.

[22] M. Chimmalgi, S. Rajesh, K. V. Anil Kumar, U. V. Asha, J. E. Jose, and K. Chandrakumari, "Problem-based learning using online platforms: An interactive alternative to mandatory e-learning during the COVID-19 pandemic," *J. Anat. Soc. India*, vol. 71, no. 3, pp. 178–185, 2022. https://doi.org/10.4103/jasi.jasi_13_22

[23] G. Gustina, A. Ananda, and A. Kosasih, "Contribution of edmodo smartphone application to support assessment activities in the social science learning process; Students Review," *International Journal of Scientific & Technology Research (IJSTR)*, vol. 9, no. 3, pp. 774–777, 2020.

[24] B. R. Bessa, S. C. dos Santos, and L. da Fonseca, "Using a virtual learning environment for problem-based learning adoption: A case study at a high school in India," in *2017 IEEE Frontiers in Education Conference (FIE)*, Indianapolis, IN, USA, 2017, pp. 1–7. https://doi.org/10.1109/FIE.2017.8190642

[25] U. Servos, B. Reiß, C. Stosch, Y. Karay, and J. Matthes, "A simple approach of applying blended learning to problem-based learning is feasible, accepted and does not affect evaluation and exam results—A just pre-pandemic randomised controlled mixed-method study," *Naunyn-Schmiedeberg's Arch Pharmacol*, vol. 396, no. 1, pp. 139–148, 2023. https://doi.org/10.1007/s00210-022-02306-3

[26] C. Anwar *et al.*, "Effect size test of learning model ARIAS and PBL: Concept mastery of temperature and heat on senior high school students," *Eurasia J. Math. Sci. T.*, vol. 15, no. 3, 2019. https://doi.org/10.29333/ejmste/103032

[27] B. R. Belland, N. J. Kim, D. M. Weiss, and J. Piland, "High school students' collaboration and engagement with scaffolding and information as predictors of argument quality during problem-based learning," 2017.

[28] M. Nowparvar, X. Chen, O. Ashour, S. G. Ozden, and A. Negahban, "Combining immersive technologies and problem-based learning in engineering education: Bibliometric analysis and literature review," in *ASEE Annual Conference and Exposition, Conference Proceedings*, 2021. http://www.scopus.com/inward/record.url?scp=85124504905&partnerID=8YFLogxK

[29] S. S. Binyamin, M. J. Rutter, and S. Smith, "The influence of computer self-efficacy and subjective norms on the students' use of learning management systems at King Abdulaziz University," *International Journal of Information and Education Technology (IJIET)*, vol. 8, no. 10, pp. 693–699, 2018. https://doi.org/10.18178/ijiet.2018.8.10.1124

[30] A. M. Mustapha *et al.*, "Students' motivation and effective use of self-regulated learning on learning management system moodle environment in higher learning institution in Nigeria," *International Journal of Information and Education Technology (IJIET)*, vol. 13, no. 1, pp. 195–202, 2023. https://doi.org/10.18178/ijiet.2023.13.1.1796

[31] H.-Y. Chang, C.-C. Chung, Y.-M. Cheng, and S.-J. Lou, "A study on the development and learning effectiveness evaluation of Problem-based Learning (PBL) virtual reality course based on intelligence network and situational learning," *Journal of Network Intelligence*, vol. 7, no. 1, pp. 1–20, 2022.

[32] C.-T. Chao *et al.*, "Fully digital problem-based learning for undergraduate medical students during the COVID-19 period: Practical considerations," *Journal of the Formosan Medical Association*, vol. 121, no. 10, pp. 2130–2134, 2022. https://doi.org/10.1016/j.jfma.2021.11.011

[33] Y. Yustina, I. Mahadi, F. Daryanes, E. Alimin, and B. Nengsih, "The effect of problem-based learning through blended learning on digital literacy of eleventh-grade students on excretory system material," *Jurnal Pendidikan IPA Indonesia*, vol. 11, no. 4, pp. 567–577, 2022. https://doi.org/10.15294/jpii.v11i4.38082

[34] J. Y. Chao, P. W. Tzeng, and H. Y. Po, "The study of problem-solving process of E-book PBL course of Atayal senior high school students in Taiwan," *Eurasia Journal of Mathematics Science and Technology Education*, vol. 13, no. 3, pp. 1001–1012, 2017. https://doi.org/10.12973/eurasia.2017.00654a

[35] E. Yh. Chung, "Facilitating learning of community-based rehabilitation through problem-based learning in higher education", *BMC Med. Educ.*, vol. 19, p. 433, 2019. https://doi.org/10.1186/s12909-019-1868-4

[36] S. Amin, S. Sumarmi, S. Bachri, S. Susilo, and A. Bashith, "The effect of problem-based hybrid learning (PBHL) models on spatial thinking ability and geography learning outcomes," *Int. J. Emerg. Technol. Learn. (iJET)*, vol. 15, no. 19, pp. 83–94, 2020. https://doi.org/10.3991/ijet.v15i19.15729

[37] M. D. Dixson, "Measuring student engagement in the online course: The online student engagement scale (OSE)," *OLJ*, vol. 19, no. 4, 2015. https://doi.org/10.24059/olj.v19i4.561

[38] E. Evendi, A. K. Al Kusaeri, M. H. H. Pardi, L. Sucipto, F. Bayani, and S. Prayogi, "Assessing students' critical thinking skills viewed from cognitive style: Study on implementation of problem-based e-learning model in Mathematics courses," *Eurasia Journal of Mathematics Science and Technology Education*, vol. 18, no. 7, p. em2129, 2022. https://doi.org/10.29333/ejmste/12161

[39] M. Anwar *et al.*, "Blended learning based project in electronics engineering education courses: A learning innovation after the Covid-19 pandemic," *Int. J. Interact. Mob. Technol. (iJIM)*, vol. 16, no. 14, pp. 107–122, 2022. https://doi.org/10.3991/ijim.v16i14.33307

[40] M. Munawaroh, N. S. Setyani, L. Susilowati, and R. Rukminingsih, "The effect of E-problem based learning on students' interest, motivation and achievement," *International Journal of Instruction*, vol. 15, no. 3, pp. 503–518, 2022. https://doi.org/10.29333/iji.2022.15328a

[41] N. Nordin *et al.*, "Social network analysis to examine the effectiveness of e-PBL with design thinking to foster collaboration: Comparisons between high and low self-regulated Learners," *Journal of Technical Education and Training (JTET)*, vol. 12, no. 4, pp. 48–59, 2022. https://doi.org/10.30880/jtet.2020.12.04.005

[42] A. Peramunugamage, H. Usoof, and J. Hapuarachchi, "Moodle mobile plugin for Problem-Based Learning (PBL) in engineering education," in *2019 IEEE Global Engineering Education Conference (EDUCON)*, Dubai, United Arab Emirates, 2019, pp. 827–835. https://doi.org/10.1109/EDUCON.2019.8725062

[43] G. Kassymova, A. Akhmetova, M. Baibekova, A. Kalniyazova, B. Mazhinov, and S. Mussina, "E-learning environments and problem-based learning," *International Journal of Advanced Science and Technology*, vol. 29, no. 7s, pp. 346–356, 2020.

[44] F. Laili and L. Lufri, "The effect of active learning in the form of scientific approach with the use of students worksheet based on Problem Based Learning (PBL) on students' biological knowledge," *J. Phys.: Conf. Ser.*, vol. 1387, no. 1, p. 012047, 2019. https://doi.org/10.1088/1742-6596/1387/1/012047

[45] H. Fibriasari, W. Andayani, T. T. A. Putri, and N. Harianja, "Learning management system now and in the future: Study case from the Indonesian University students," *International Journal of Information and Education Technology (IJIET)*, vol. 13, no. 1, pp. 158–165, 2023. https://doi.org/10.18178/ijiet.2023.13.1.1791

[46] O. Filho and S. dos Santos, "Are we ready for problem-based learning? A proposal of institutional diagnosis in computing higher education," in *Proceedings of the 13th International Conference on Computer Supported Education*, 2021, vol. 1, pp. 413–424. https://doi.org/10.5220/0010433604130424

[47] Y. Yustina, I. Mahadi, D. Ariska, A. Arnentis, and D. Darmadi, "The effect of e-learning based on the problem-based learning model on students' creative thinking skills during the Covid-19 pandemic," *International Journal of Instruction*, vol. 15, no. 2, pp. 329–348, 2022. https://doi.org/10.29333/iji.2022.15219a

[48] G. A. Putri, I. Dewata, B. Oktavia, and D. Kurniawati, "Meta-analysis of the implementation of E-modules and the effectiveness of using chemical bonding e-modules based on scientific approaches against student X learning outcomes in Pariaman City," *International Journal of Innovative Science and Research Technology (IJISRT)*, vol. 5, no. 7, pp. 1210–1214, 2020. https://doi.org/10.38124/IJISRT20JUL797

[49] H. Hautopp and S. Ejsing-Duun, "Spaces of joint inquiry through visual facilitation and representations in higher education: An exploratory case study," *The Electronic Journal of E-Learning (EJEL)*, vol. 18, no. 5, pp. 373–386, 2020. https://doi.org/10.34190/JEL.18.5.001

[50] W. Isnaeni, E. Rudyatmi, S. Ridlo, S. Ingesti, and L. R. Adiani, "Improving students' communication skills and critical thinking ability with ICT-oriented problem-based learning and the assessment instruments with HOTS criteria on the immune system material," *J. Phys.: Conf. Ser.*, vol. 1918, no. 5, p. 052048, 2021. https://doi.org/10.1088/1742-6596/1918/5/052048

[51] D. Kilińska and T. Ryberg, "Connecting learning analytics and problem-based learning – Potentials and challenges," *Journal of Problem Based Learning in Higher Education*, vol. 7, no. 1, pp. 1–24, 2019. https://doi.org/10.5278/OJS.JPBLHE.V7I1.2545

[52] F. Martin and D. U. Bolliger, "Engagement matters: Student perceptions on the importance of engagement strategies in the online learning environment," *OLJ*, vol. 22, no. 1, 2018. https://doi.org/10.24059/olj.v22i1.1092

[53] D. McIntosh, W. Al-Nuaimy, A. A. Ataby, I. Sandall, V. Selis, and S. Allen, "Gamification approaches for improving engagement and learning in small and large engineering classes," *International Journal of Information and Education Technology (IJIET)*, vol. 13, no. 9, pp. 1328–1337, 2023. https://doi.org/10.18178/ijiet.2023.13.9.1935

[54] M. Munawaroh, N. S. Setyani, L. Susilowati, Q. Sholihah, and K. A. Lenggono, "Application of electronic problem-based learning (E-PBL) during the COVID-19 pandemic in entrepreneurial attitude," *Eurasian Journal of Educational Research*, vol. 95, pp. 156–175, 2021. https://eric.ed.gov/?id=EJ1321961

[55] D. Phelan, T. Barrett, and O. Lennon, "Does interprofessional problem-based learning (iPBL) develop health professional students' interprofessional competences? A systematic review of contexts, mechanisms and outcomes," *IJPBL*, vol. 16, no. 1, 2022. https://doi.org/10.14434/ijpbl.v16i1.31647

[56] J. M. Rahmawati, S. R. Lestari, and H. Susilo, "Implementation of e-module endocrine system based on problem-based learning (PBL) to improve scientific literacy and cognitive learning outcome," *AIP Conference Proceedings*, vol. 2330, no. 1, p. 030024, 2021. https://doi.org/10.1063/5.0043175

[57] N. S. Raj and R. V. G., "An approach for early prediction of academic procrastination in e-learning environment," *International Journal of Information and Education Technology (IJIET)*, vol. 13, no. 1, pp. 73–81, 2023. https://doi.org/10.18178/ijiet.2023.13.1.1782

[58] D. Arwidiyarti, Khaerudin, and B. Wibawa, "Implementation of the E-PBL learning model using the collassion learning-app to maximize the collaboration and student discussion process in solving problems," *International Journal of Information and Education Technology (IJIET)*, vol. 12, no. 11, pp. 1237–1242, 2022. https://doi.org/10.18178/ijiet.2022.12.11.1744
[59] C. E. Rustana, S. Aminah, and A. S. Budi, "The development of harmonic oscillation e-module based on problem-based learning (pbl) for helping improvement of students' higher order thinking skills (hots)," *J. Phys.: Conf. Ser.*, vol. 1869, no. 1, p. 012174, 2021. https://doi.org/10.1088/1742-6596/1869/1/012174
[60] M. C. Sáiz-Manzanares, C. I. García Osorio, J. F. Díez-Pastor, and L. J. Martín Antón, "Will personalized e-Learning increase deep learning in higher education?" *Information Discovery and Delivery (IDD)*, vol. 47, no. 1, pp. 53–63, 2019. https://doi.org/10.1108/IDD-08-2018-0039
[61] I. Saleem, M. A. Shamsi, and H. Magd, "Impact assessment of ease and usefulness of online teaching in higher education in post COVID era," *International Journal of Information and Education Technology (IJIET)*, vol. 13, no. 1, pp. 102–113, 2023. https://doi.org/10.18178/ijiet.2023.13.1.1785
[62] N. Meng, Y. Dong, D. Roehrs, and L. Luan, "Tackle implementation challenges in project-based learning: A survey study of PBL e-learning platforms," *Education Tech. Research Dev.*, vol. 71, no. 3, pp. 1179–1207, 2023. https://doi.org/10.1007/s11423-023-10202-7
[63] G. Nicholus, C. M. Muwonge, and N. Joseph, "The role of problem-based learning approach in teaching and learning Physics: A systematic literature review," *F1000Res.*, vol. 12, p. 951, 2023. https://doi.org/10.12688/f1000research.136339.2
[64] J. F. Hair, J. J. Risher, M. Sarstedt, and C. M. Ringle, "When to use and how to report the results of PLS-SEM," *European Business Review (EBR)*, vol. 31, no. 1, pp. 2–24, 2019. https://doi.org/10.1108/EBR-11-2018-0203
[65] M. Bellaj, A. B. Dahmane, S. Boudra, and M. L. Sefian, "Educational data mining: Employing machine learning techniques and hyperparameter optimization to improve students' academic performance," *International Journal of Online and Biomedical Engineering (iJOE)*, vol. 20, no. 3, pp. 55–74, 2024. https://doi.org/10.3991/ijoe.v20i03.46287
[66] M. A. Adijaya, I. W. Widiana, I. G. L. Agung Parwata, and I. G. W. Suwela Antara, "Bloom's taxonomy revision-oriented learning activities to improve procedural capabilities and learning outcomes," *International Journal of Educational Methodology*, vol. 9, no. 1, pp. 261–270, 2023. https://doi.org/10.12973/ijem.9.1.261

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