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Development of an Artificial Intelligence-Assisted Project-Based Learning Model in Economics Learning at Generasi Bintang Senior High School Bitung

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A B S T R A C T
The rapid development of digital technology and the demands of 21st-century education require innovative learning models that promote higher-order thinking skills, creativity, collaboration, and digital literacy. However, economics learning at the senior high school level is still predominantly theoretical and has not optimally integrated technology to support active and contextual learning. Therefore, this study aimed to develop an Artificial Intelligence-assisted Project-Based Learning (AI-PjBL) model for economics learning at Generasi Bintang Senior High School Bitung. The research participants involved senior high school students, while data were collected through interviews, questionnaires, observations, expert validation sheets, and learning achievement tests. The results indicated that the developed AI-PjBL model achieved a high level of validity, with an average expert validation score of 89%, categorized as highly valid. The practicality test results showed positive responses from both teachers and students, with average practicality scores of 91% and 87.6%, respectively, indicating that the model was highly practical for classroom implementation. Furthermore, the effectiveness test demonstrated that the experimental group achieved higher posttest scores and N-Gain values compared to the control group.

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INTRODUCTION

The development of 21st-century education has encouraged a significant transformation in learning paradigms to respond to rapid social, technological, and global changes (Indarta et al., 2022). Education is no longer merely oriented toward the transfer of theoretical knowledge but is increasingly directed toward the development of higher-order thinking skills (HOTS), creativity, problem-solving abilities, collaboration, communication, and digital literacy as essential competencies in the digital era (Anderson & Krathwohl, 2001; Bloom, 1956). This transformation has shifted the learning approach from teacher-centered instruction toward student-centered learning that actively engages learners in constructing knowledge and solving authentic problems. In this context, the integration of digital technology has become an inevitable necessity in creating interactive, flexible, and contextual learning experiences. The rapid advancement of digital transformation in the era of Society 5.0 has also influenced educational practices and learning systems in various disciplines (Ananda et al., 2023). One of the emerging technologies increasingly adopted in education is Artificial Intelligence (AI), which has the potential to support personalized learning, expand access to information, and improve the effectiveness of instructional processes. The presence of AI in education provides opportunities for developing innovative learning models that encourage active student participation through project-based activities, exploration, and real-world problem solving relevant to everyday life (Jurnal BasicEdu, 2025).

Despite these developments, the implementation of economics learning at the senior high school level continues to face several challenges. Economics instruction in many schools remains predominantly theoretical and relies heavily on conventional teaching methods, resulting in limited student engagement during the learning process. Consequently, students tend to memorize concepts without fully understanding their application to real economic phenomena encountered in society. In addition, students' abilities to analyze contextual economic issues, think critically, and solve authentic economic problems are still relatively low. Learning activities have also not optimally facilitated the development of collaboration and creativity skills through meaningful and authentic projects related to students' social and economic environments. Furthermore, the integration of intelligent technologies, including Artificial Intelligence, into economics learning remains limited and has not been systematically implemented in classroom practices. As a result, economics education has not yet fully addressed the demands of 21st-century learning, which emphasizes adaptive, innovative, technology-oriented, and student-centered competencies.

One of the pedagogical approaches considered relevant to addressing the challenges of 21st-century learning is Project-Based Learning (PjBL). PjBL is a student-centered instructional model that emphasizes active learning through the completion of meaningful projects based on real-world problems and contextual experiences. Through project-oriented activities, students are encouraged to collaborate, explore ideas, make decisions, and construct knowledge independently. Previous studies have shown that PjBL contributes

significantly to the development of collaboration skills, creativity, learner autonomy, problem-solving abilities, and critical thinking skills (Haryadi & Jannah, 2022). In addition, PjBL promotes deeper learning experiences because students are directly involved in inquiry, investigation, and the production of authentic outputs.

The theoretical foundation of PjBL is closely related to constructivist learning theory, which emphasizes that knowledge is actively constructed through meaningful experiences and social interaction (Haryadi & Jannah, 2022). In the context of economics education, PjBL is particularly relevant because economics learning requires students to understand and analyze economic phenomena that occur in everyday life. Through project-based activities, students can engage in economic case analyses, entrepreneurship projects, market studies, and financial literacy practices that enable them to connect theoretical concepts with practical applications. Therefore, the implementation of PjBL in economics learning has the potential to create more meaningful, contextual, and experiential learning experiences while simultaneously improving students' higher-order thinking skills and real-world problem-solving competencies.

Alongside the growing implementation of innovative learning models, the advancement of Artificial Intelligence (AI) has also created new opportunities for transforming educational practices. AI has increasingly been integrated into education as a learning assistant capable of supporting both teachers and students in the teaching and learning process. The use of AI technologies enables more personalized learning experiences by adapting instructional materials, feedback, and learning pathways according to students' individual needs and abilities. In addition, AI can facilitate the exploration of information, data analysis, and project idea generation, thereby supporting students in conducting inquiry-based and project-oriented learning activities more effectively. Various AI-based tools, such as ChatGPT, generative AI applications, AI analytics, and adaptive learning systems, have demonstrated considerable potential in enhancing student engagement, improving learning efficiency, and increasing classroom interactivity (Jurnal BasicEdu, 2025). Previous studies have also reported that the integration of AI into project-based learning environments can improve instructional effectiveness and support students' critical thinking development (Baskara et al., 2024). Similarly, Herianto (2024) found that AI-based learning approaches positively influenced students' learning outcomes and engagement in classroom activities. In project-based learning environments, AI can function as a collaborative learning partner that assists students in brainstorming ideas, analyzing economic data, developing project designs, and accessing relevant information more efficiently. Consequently, the integration of AI into Project-Based Learning offers a promising innovation for developing more adaptive, interactive, and technology-enhanced economics learning in the digital era.

Based on the issues and potential solutions described above, this study aims to develop an Artificial Intelligence-assisted Project-Based Learning (AI-assisted PjBL) model for economics learning at Generasi Bintang Senior High School

Bitung. The proposed model is expected to enhance the quality of learning by creating more interactive, contextual, and student-centered learning experiences while fostering students' higher-order thinking skills, problem-solving abilities, creativity, and collaboration skills. In addition, this study seeks to examine the validity of the developed model through expert evaluation, assess its practicality in classroom implementation, and evaluate its effectiveness in improving students' learning outcomes and critical thinking skills in economics learning. Through the integration of Artificial Intelligence into Project-Based Learning, this research is expected to contribute to the development of innovative and technology-enhanced instructional models that are relevant to the demands of 21st-century education

LITERATURE REVIEW

Project-Based Learning in Economics Education

Project-Based Learning (PjBL) is widely recognized as an instructional approach that emphasizes students' active engagement in the learning process through the completion of meaningful projects related to real-world problems. This learning model is grounded in the principles of student-centered learning, where students are encouraged to investigate issues, collaborate with peers, and produce authentic outcomes that demonstrate their understanding and practical competencies. Through project-oriented activities, students are not merely passive recipients of information; instead, they actively construct knowledge through exploration, inquiry, and social interaction. Recent educational studies have highlighted that PjBL supports the development of essential 21st-century competencies, including critical thinking, collaboration, creativity, communication, and problem-solving skills.

Theoretically, PjBL is strongly associated with constructivist learning theory, particularly the perspectives proposed by Piaget and Vygotsky. Constructivism emphasizes that knowledge is actively constructed by learners through meaningful experiences and interactions within their social environment. Piaget's cognitive constructivism highlights the importance of individual exploration and cognitive development, whereas Vygotsky's social constructivism underlines the role of social interaction and collaborative learning in knowledge construction. In the context of economics education, these theoretical perspectives are highly relevant because economics learning requires students to understand abstract concepts and relate them to authentic economic phenomena encountered in everyday life, such as inflation, entrepreneurship, market dynamics, and financial decision-making. Consequently, PjBL provides opportunities for students to connect theoretical economic concepts with practical and contextual experiences.

Artificial Intelligence in Education

Artificial Intelligence (AI) refers to computational technologies that enable computer systems to perform tasks that typically require human intelligence, such as data analysis, decision-making, language processing, and pattern recognition. In recent years, AI has emerged as one of the most transformative technologies in the field of education, offering innovative opportunities to enhance teaching and learning processes. The integration of AI into educational

settings supports the development of more adaptive, interactive, and personalized learning environments that align with the demands of 21st-century education. As digital transformation continues to reshape educational practices, AI is increasingly utilized as a learning support tool that assists students in understanding learning materials more effectively and efficiently.

One of the primary advantages of AI in education is its ability to provide rapid access to information and immediate feedback. AI-powered systems can assist students in searching for relevant learning resources, analyzing information, identifying errors, and evaluating their work independently. This capability enables learning experiences to become more personalized and responsive to individual students' needs, learning styles, and levels of understanding.

In addition, AI technologies support adaptive learning processes by adjusting instructional content and recommendations based on students' progress and performance. Consequently, AI contributes to improving learning efficiency while simultaneously encouraging students to become more autonomous and self-directed learners.

METHODOLOGY

This study employed a Research and Development (R&D) approach aimed at developing an Artificial Intelligence-assisted Project-Based Learning (AI-assisted PjBL) model and examining its effectiveness in economics learning at the senior high school level. Research and Development was selected because this study focused not only on generating an instructional product but also on evaluating the validity, practicality, and effectiveness of the developed learning model in real classroom settings. The development procedure adopted the ADDIE instructional design model, which consists of five main stages: Analysis, Design, Development, Implementation, and Evaluation. The ADDIE model was selected due to its systematic and flexible framework for developing educational products and instructional innovations.

The first stage was the analysis phase, which aimed to identify learning needs, student characteristics, and problems encountered in economics learning. At this stage, preliminary studies were conducted through interviews with economics teachers and questionnaires distributed to students at Generasi Bintang Senior High School Bitung, North Sulawesi, Indonesia. The collected data were used to examine existing instructional practices, students' learning difficulties, the level of technology integration in classroom learning, and the need for innovative learning models that support 21st-century competencies.

The second stage was the design phase, which involved designing the AI-assisted PjBL model and developing supporting instructional materials. These materials included lesson plans, student worksheets, project guidelines, assessment instruments, and learning activities integrating Artificial Intelligence tools into project-based economics learning. The design process also focused on aligning learning objectives, instructional activities, and assessment strategies with higher-order thinking skills and student-centered learning principles.

The third stage was the development phase, during which the prototype of the learning model and instructional materials were developed and validated by experts. The validation process involved experts in economics education, instructional design, and educational technology or learning media. Expert evaluations focused on the content validity, instructional appropriateness, technological integration, and usability of the developed model. Feedback and recommendations provided by the validators were used as the basis for revising and improving the product before implementation.

The fourth stage was the implementation phase, which consisted of limited trials and field testing. The developed AI-assisted PjBL model was implemented in economics learning activities involving students at Generasi Bintang Senior High School Bitung. This stage aimed to evaluate the practicality and effectiveness of the model in real classroom situations. During implementation, observations were conducted to examine student participation, classroom interaction, and the feasibility of integrating Artificial Intelligence into project-based learning activities. The final stage was the evaluation phase, which aimed to assess the overall quality of the developed learning model and conduct final revisions based on the implementation results. Evaluation was carried out continuously throughout each stage of the development process to ensure that the final product met the expected standards of validity, practicality, and effectiveness.

The research participants consisted of senior high school students at Generasi Bintang Senior High School Bitung selected as the research sample. Data were collected through interviews, questionnaires, classroom observations, and learning achievement tests. Interviews and questionnaires were used to identify learning needs and gather responses regarding the developed model, while observations were conducted to evaluate classroom implementation and student engagement. Learning achievement tests were administered to measure students' learning outcomes and critical thinking skills after participating in the AI-assisted PjBL activities. Data analysis was conducted using descriptive and quantitative techniques. Expert validation data were analyzed using percentage scores to determine the validity level of the developed model. Meanwhile, the effectiveness of the model was analyzed using the N-Gain formula to examine the improvement in students' learning outcomes before and after the implementation of the AI-assisted Project-Based Learning model

RESEARCH RESULT

I. Development of the AI-Integrated Project-Based Learning Model

This study developed an Artificial Intelligence-Integrated Project-Based Learning (AI-PjBL) model aimed at improving students' higher-order thinking skills in economics learning at the senior high school level. The model integrates Project-Based Learning principles with Artificial Intelligence technologies to support inquiry, collaboration, problem-solving, and contextual learning activities. The developed model consists of six major instructional stages as follows:

1. **Determining Essential Problems or Questions**. At the beginning of the learning process, students identify authentic economic problems relevant to real-life situations. Teachers facilitate students in formulating essential questions that encourage critical thinking, problem analysis, and inquiry-based learning activities.
2. **Designing the Project Plan**. In this stage, students collaboratively develop project plans, determine learning objectives, identify resources, and formulate strategies for solving the selected economic problems. This activity encourages collaborative learning and promotes students' responsibility in managing project tasks.
3. **Organizing the Project Schedule**. Students prepare timelines and allocate responsibilities among group members to ensure effective project implementation. This stage helps students develop time-management, organizational, and teamwork skills throughout the learning process.
4. **Implementing and Monitoring the Project with AI Assistance**. This stage represents the primary innovation of the developed model. Students utilize Artificial Intelligence technologies to support information searching, economic data analysis, idea generation, and project report preparation. AI tools assist students in exploring relevant references, analyzing economic trends, and developing solutions to contextual economic problems. Teachers simultaneously monitor students' progress and provide instructional guidance during project implementation.
5. **Presenting Project Outcomes**. Students present the results of their projects through presentations, reports, or multimedia-based products. This activity encourages students to communicate ideas effectively, defend their arguments, and engage in academic discussions with peers and teachers.
6. **Conducting Evaluation and Reflection**. At the final stage, teachers and students evaluate the project outcomes and reflect on the overall learning experience. Reflection activities are intended to help students identify strengths, challenges, and improvements needed for future learning activities.

The integration of Artificial Intelligence within the Project-Based Learning process enriched students' learning experiences by facilitating broader access to information, supporting independent learning, and improving the efficiency of project completion. In addition, the developed AI-PjBL model promoted active participation, collaboration, critical thinking, and contextual problem-solving skills that are essential in 21st-century learning environments

Expert Validation Results

Prior to classroom implementation, the developed AI-Integrated Project-Based Learning (AI-PjBL) model underwent an expert validation process to evaluate its feasibility and instructional quality. The validation involved three categories of experts, namely economics content experts, instructional model experts, and educational media experts. The purpose of this validation process was to assess the appropriateness of the developed model from the perspectives

of content quality, instructional design, and AI integration. The validation results are presented in Table 1.

Table 1. Expert Validation Results of the AI-PjBL Model

No	Assessment Aspect	Mean Score	Percentage	Category
1	Content Feasibility	4.45	89%	Highly Valid
2	Instructional Model Feasibility	4.4	88%	Highly Valid
3	Media and AI Integration Feasibility	4.5	90%	Highly Valid
	Average	**4.45**	**89%**	**Highly Valid**

The findings indicate that the developed AI-PjBL model achieved an overall average validation score of 4.45, equivalent to 89%, which falls within the "highly valid" category. The highest validation result was obtained in the aspect of media and AI integration feasibility, with a percentage score of 90%. This result demonstrates that the integration of Artificial Intelligence within the learning model was considered appropriate, relevant, and supportive of the instructional objectives in economics learning.

In addition, the validation results from instructional model experts confirmed that the developed learning syntax, project-based activities, and student-centered learning procedures were systematically designed and aligned with the principles of Project-Based Learning. Meanwhile, content experts stated that the economics materials incorporated into the model were relevant to curriculum objectives and capable of facilitating contextual and meaningful learning experiences.

Overall, the expert validation findings suggest that the developed AI-PjBL model meets the required standards of feasibility and instructional quality for implementation in economics learning at the senior high school level. The validation process also provided several recommendations for minor revisions related to instructional clarity, technical guidance for AI utilization, and the refinement of project assessment indicators prior to field implementation

III. Practicality Test Results

The practicality test was conducted to evaluate the ease of use and applicability of the developed AI-Integrated Project-Based Learning (AI-PjBL) model from the perspectives of both teachers and students during the learning process. The practicality assessment focused on instructional clarity, usability, relevance to economics learning, student engagement, and the effectiveness of AI integration in supporting project-based activities. The results of the teacher responses are presented in Table 2.

Table 2. Teachers' Responses toward the AI-PjBL Model

Assessment Aspect	Percentage	Category
Ease of model implementation	90%	Highly Practical

Clarity of instructional procedures	92%	Highly Practical
Suitability for economics learning materials	91%	Highly Practical
Average	91%	Highly Practical

The findings indicate that teachers perceived the developed AI-PjBL model as highly practical for classroom implementation. The highest score was obtained in the aspect of instructional procedure clarity, suggesting that the learning stages and project activities were systematically organized and easy to follow. Teachers also reported that the integration of Artificial Intelligence tools supported classroom learning activities and enhanced students' participation during project implementation. The students' responses toward the implementation of the model are presented in Table 3.

Table 3. Students' Responses toward the Implementation of the AI-PjBL Model

Assessment Aspect	Percentage	Category
Interest in learning activities	88%	Highly Practical
Ease of understanding learning materials	86%	Highly Practical
Benefits of AI utilization	89%	Highly Practical
Average	**87.60%**	**Highly Practical**

Based on the students' responses, the developed model also demonstrated a high level of practicality. Students expressed greater interest and motivation in participating in project-based learning activities supported by Artificial Intelligence. In addition, students reported that AI tools helped them understand economics concepts more effectively, search for relevant information efficiently, and complete project tasks collaboratively.

The positive responses indicate that the integration of AI within the Project-Based Learning process created a more engaging, interactive, and meaningful learning experience.

Effectiveness Test Results

The effectiveness test was conducted to examine the impact of the AI-Integrated Project-Based Learning (AI-PjBL) model on students' learning outcomes, particularly in terms of higher-order thinking skills (HOTS) in economics learning. The evaluation was carried out using a pretest-posttest design involving an experimental group and a control group. The experimental group received instruction using the AI-PjBL model, while the control group was taught using conventional learning methods. The comparison of pretest and posttest scores is presented in Table 4.

Table 4. Pretest and Posttest Results

Group	N	Mean Pretest Score	Mean Posttest Score
Experimental Group (AI-PjBL)	30	56.4	84.2
Control Group (Conventional Learning)	30	55.8	71.5

The results indicate that both groups experienced improvements in learning outcomes after the instructional process. However, the experimental group demonstrated a substantially higher increase in posttest scores compared to the control group. The average posttest score of students taught using the AI-PjBL model reached 84.2, whereas the control group achieved an average score of 71.5. These findings suggest that the integration of Artificial Intelligence within Project-Based Learning contributed positively to improving students' higher-order thinking skills and conceptual understanding in economics learning.

To further examine the level of learning improvement, the N-Gain analysis was conducted for both groups. The results are presented in Table 5.

Table 5. N-Gain Analysis Results

Group	Pretest	Posttest	N-Gain	Category
Experimental Group	56.4	84.2	0.64	Moderate
Control Group	55.8	71.5	0.35	Moderate

The N-Gain analysis revealed that the experimental group achieved a higher N-Gain score (0.64) compared to the control group (0.35). Although both groups were categorized within the moderate improvement category, the experimental group demonstrated significantly greater learning gains. This finding indicates that the implementation of the AI-PjBL model was more effective in improving students' learning outcomes than conventional instructional approaches.

The higher improvement observed in the experimental group may be attributed to several factors. First, the project-based learning process encouraged students to actively engage in problem-solving, investigation, and collaborative learning activities. Second, the integration of Artificial Intelligence technologies supported students in accessing information, analyzing economic data, and generating project ideas more efficiently.

Third, the contextual and student-centered nature of the AI-PjBL model created more meaningful learning experiences that facilitated deeper conceptual understanding and critical thinking development

DISCUSSION

The findings of this study demonstrate that the developed Artificial Intelligence-Integrated Project-Based Learning (AI-PjBL) model possesses high levels of validity, practicality, and effectiveness in economics learning at the senior high school level. The expert validation results indicate that the model is pedagogically appropriate, systematically designed, and relevant to the characteristics of 21st-century learning. In addition, the positive responses from

teachers and students suggest that the model is practical and feasible for classroom implementation. These findings imply that the integration of Artificial Intelligence within Project-Based Learning can create a more interactive, contextual, and student-centered learning environment.

The effectiveness test results further reveal that the AI-PjBL model significantly improved students' learning outcomes and higher-order thinking skills compared to conventional instructional approaches. The higher posttest and N-Gain scores achieved by the experimental group indicate that students benefited from active involvement in project-based learning activities supported by AI technologies. This improvement can be attributed to the characteristics of Project-Based Learning, which encourages students to investigate authentic problems, collaborate with peers, and construct knowledge through meaningful learning experiences. Through project completion activities, students were not only required to understand theoretical economic concepts but also to apply these concepts in solving contextual economic problems encountered in everyday life.

Another important finding of this study is the contribution of Artificial Intelligence as a cognitive and instructional support tool within the learning process. The use of AI technologies enabled students to access information more efficiently, analyze economic data more accurately, and explore project ideas more creatively. AI-assisted learning activities also promoted students' learning autonomy by allowing them to independently search for references, evaluate information, and develop alternative solutions to economic problems. Consequently, the integration of AI enriched students' learning experiences and supported the development of analytical thinking, creativity, and digital literacy skills that are essential in the digital era.

Furthermore, the implementation of the AI-PjBL model increased students' engagement and motivation during learning activities. Students demonstrated greater participation in discussions, collaborative work, and project presentations because the learning activities were directly connected to authentic and relevant economic issues. The integration of technology also contributed to creating a more dynamic and interactive classroom atmosphere. These findings support the view that technology-enhanced learning environments can positively influence students' motivation and participation in the learning process.

The results of this study are consistent with previous research indicating that the integration of technology into Project-Based Learning contributes positively to the quality of instructional processes and the development of 21st-century competencies. Previous studies have emphasized that project-based learning supported by digital technologies can improve critical thinking, collaboration, creativity, and problem-solving skills. Similarly, the findings of this study confirm that Artificial Intelligence can function not only as a technological tool but also as a learning partner that facilitates inquiry, exploration, and knowledge construction in economics education.

Therefore, the developed AI-PjBL model can be considered an innovative instructional alternative that is relevant to the demands of contemporary education in the digital era. The model provides opportunities for teachers to implement more adaptive and technology-oriented learning practices while simultaneously supporting students in developing higher-order thinking skills and digital competencies required in modern society. Nevertheless, further studies involving broader educational contexts and larger sample sizes are necessary to examine the long-term effectiveness and scalability of the developed model across different learning environments.

CONCLUSIONS AND RECOMMENDATIONS

Based on the findings of this study, it can be concluded that the developed Artificial Intelligence-assisted Project-Based Learning (AI-PjBL) model is valid, practical, and effective for implementation in economics learning at the senior high school level. The expert validation results confirmed that the model met the required standards in terms of instructional design, content feasibility, and AI integration. In addition, the practicality test demonstrated that both teachers and students responded positively to the implementation of the model, indicating that it was easy to use and suitable for classroom learning activities.

The effectiveness test further revealed that the AI-PjBL model significantly improved students' learning outcomes and higher-order thinking skills compared to conventional learning approaches. The integration of project-based activities with Artificial Intelligence technologies encouraged students to actively participate in the learning process, engage in collaborative problem-solving, and apply economic concepts to authentic real-world situations. Furthermore, the use of AI tools supported students in accessing information, analyzing economic data, and developing creative solutions more effectively.

Therefore, the AI-PjBL model can be considered an innovative instructional alternative that is relevant to the demands of digital-era education and 21st-century learning. The model not only enhances students' engagement and critical thinking skills but also supports the development of digital literacy, creativity, collaboration, and problem-solving competencies needed to face future economic and societal challenges. Future research is recommended to implement and evaluate the model in broader educational contexts and across different subject areas to further examine its long-term effectiveness and adaptability

ADVANCED RESEARCH

This study has several limitations that should be acknowledged. First, the research was conducted only at SMK Negeri 1 Tombariri, which may limit the generalizability of the findings to other educational contexts, particularly schools with different technological infrastructures, student characteristics, or institutional policies. Second, the study employed a qualitative descriptive approach that focused on exploring the implementation process and participants' experiences rather than quantitatively measuring the effectiveness of interactive learning media on students' academic achievement. Therefore, the findings primarily provide contextual and interpretative insights into the use of interactive learning media in vocational education settings. Third, the study was

conducted within a limited research period, which may not fully capture the long-term impact of interactive learning media on students' learning outcomes and digital competencies.

Future research is recommended to expand the scope of investigation by involving multiple vocational schools or different educational levels to obtain broader and more comprehensive findings regarding the implementation of interactive learning media. Further studies may also employ mixed-methods or experimental research designs to quantitatively examine the effectiveness of specific interactive learning platforms on students' academic performance, motivation, critical thinking skills, or digital literacy. In addition, future researchers are encouraged to explore the long-term sustainability of interactive learning media implementation, including teachers' digital readiness, institutional support systems, and the influence of educational policies on technology integration in schools. Research focusing on the development of innovative digital learning models or school-based interactive learning frameworks may also contribute significantly to the advancement of technology-enhanced learning in vocational education.

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