JPPIPA 11(10) (2025)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

Development of Science E-Modules Based on PjBL (Project Based Learning) in Grade VIII to Improve Students' Critical Thinking Skills

Suci Ana Yolanda[1*], Yohandri[2]

[1] Master of Physics Education, FMIPA, Universitas Negeri Padang, Padang, Indonesia.
[2] Physics Education, FMIPA, Universitas Negeri Padang, Padang, Indonesia.

Received: July 23, 2025
Revised: September 21, 2025
Accepted: October 25, 2025
Published: October 31, 2025

Corresponding Author:
Suci Ana Yolanda
sucianayolanda4@gmail.com

DOI: 10.29303/jppipa.v11i10.12283

Abstract: Exercise questions used by educators are still in the form of questions that are classified as easy and have not been able to improve the ability to think critically One of the learning needs of learners is a learning resource that is in accordance with the development of the 21st century. (e-module). The purpose of this research is to produce a project-based learning (PjBL)-based science e-module with valid, practical, and effective categories.with valid, practical, and effective categories. This research is a type of research and development with the ADDIE development model, namely Analyze, Design, Development, Implementation, Evaluation. The research instrument consists of a preliminary questionnaire, validation instrument, practicality instrument, and effectiveness instrument. Data analysis techniques consist of preliminary study data, validity data, practicality data, and effectiveness data. Based on the results of the assessment of project-based learning (PjBL) based science e-modules conducted by experts, the results obtained with an average validation by media experts, material experts and linguists are in the valid category. The practicality of e-modules assessed by teachers and students of SMPN 6 Padang Panjang is in the practical and very practical categories. Effectiveness, project-based learning (PjBL) based science e-modules are in the effective category. Based on the results of the study, it can be concluded that project-based learning-based science e-modules meet the criteria of valid, practical, and effective.

Keywords: Critical thinking; E-module; Project based learning

Introduction

In the 21st century, the world of education is required to continue to evolve and become more accessible to all groups. One factor driving this change is the emergence of the Industrial Revolution 4.0, an era based on digital technology and automation (Javaid et al., 2024; Horváth & Szabó, 2019). The Industrial Revolution 4.0 has brought significant changes to various aspects of life, including the education sector. This era is characterized by the integration of digital, physical, and biological technologies, fundamentally changing the way people live, work, and learn. This transformation requires the education system to not only keep pace with technological developments but also adapt learning methods to produce adaptive, creative, and competitive human resources in the digital age (Blanka et al., 2022; Kraus et al., 2021). In an era where technology is increasingly becoming an integral part of everyday life, the transformation towards smart buildings is inevitable. The use of technology in building infrastructure, such as the Internet of Things (IoT), automation systems, and artificial intelligence, enables the creation of more efficient, safe, and comfortable environments for occupants (Sivasankari & Rathika, 2025). The development of communication has brought

How to Cite:
Yolanda, S. A., & Yohandri. (2025). Development of Science E-Modules Based on PjBL (Project Based Learning) in Grade VIII to Improve Students' Critical Thinking Skills. *Jurnal Penelitian Pendidikan IPA*, *11*(10), 873–881. https://doi.org/10.29303/jppipa.v11i10.12283

significant changes to various aspects of life, including education. Faster and more widespread communication allows the learning process to be more effective, collaborative, and accessible to various groups (Haleem et al., 2022).

Along with the increasingly modern era, various sectors have also experienced accelerated change, particularly through the use of technology. One example is in education, where various media are now used as supporting tools in the learning process (Abdulrahaman et al., 2020). Electronic modules (e-modules) are an extension of printed modules into a digital format that can be accessed through electronic devices. E-modules are compiled in electronic format and can be run on computers or other devices. Unlike printed modules, e-modules can display content in the form of text, images, animations, and even videos, making them more interactive and engaging. With technological advances, e-modules can now also be accessed via smartphones, making learning easier anytime and anywhere (Khotimah et al., 2024). In addition to developing learning media, students must also possess 21st-century skills, known as the 4Cs. These skills include creative thinking, critical thinking and problem-solving, communication, and collaboration. These four skills are crucial for equipping students to face the challenges of the dynamic and complex modern world (Herlinawati et al., 2024).

Critical thinking skills are part of higher-order thinking skills that play a crucial role in improving students' analytical abilities. These abilities enable students to evaluate information in-depth, make informed decisions, and solve problems logically and systematically. Therefore, developing critical thinking skills in the learning process is a strategic step to improve the overall quality and learning outcomes of students (Golden, 2023). Project-Based Learning (PjBL) is a form of active learning that focuses on direct student involvement in the learning process. Simply put, PjBL can be defined as a learning model that links the use of technology to solving everyday life problems relevant to students' experiences, both in individual contexts and through school projects. Through this approach, students are encouraged to think critically and creatively, and to collaborate in completing project-based assignments both independently and collaboratively. According to Rehman et al. (2024), the project-based learning model has enormous potential to create more engaging, meaningful, and relevant learning experiences for students. By actively involving students in solving real-life problems through projects, learning becomes more contextual and fosters motivation and 21st-century skills.

Based on several previous studies, it shows that the development of e-modules is feasible and can be used in genetics learning to improve the critical thinking skills of Biology Education students at the University of Jambi. This is proven by Anjani et al. (2024), with the title of her research "Development of Molecular Genetics E-Modules Based on STEM-Project Based Learning (PjBL) Integrated with Socio-Scientific Issues (SSI) to Improve the Critical Thinking Skills of Biology Education Students.", the same research was also conducted by (Rasyih et al., 2024), with the title "Development of E-Practicum Guide for Laboratory Management Techniques Based on PjBL to Improve 21st Century Learning" in their research stated that the development of electronic laboratory management technique practicum guides based on the Project Based Learning (PjBL) learning model is feasible to be used to improve 21st century learning.

Several research results that have been conducted show that improving critical thinking skills can be done by using the Project Based Learning learning model, research by Selano et al. (2024), with the research title "Development of E-Modules Based on Project Based Learning to Improve Critical Thinking Skills Fifth-Grade Students" results from the study indicate a difference in students' critical thinking skills before and after the e-module treatment was implemented. This indicates a positive impact on the use of e-modules and an increase in the critical thinking skills scores of fifth-grade students at SDN 5 Sumber Rejo. Based on interviews conducted by the researcher with the science teacher, Mrs. Dwi Suryani Alfa, S.Pd., at SMPN 6 Padang Panjang in eighth-grade students, it was discovered that students experienced difficulty performing calculations, particularly in physics. Furthermore, the learning method used was still dominated by lectures, where the teacher only delivered the material verbally while students passively listened. According to the teacher, this was done because physics material was considered difficult to understand without direct explanation from the teacher.

As a result, students tended to be less active in the learning process and had difficulty grasping the concepts presented. Therefore, in this study, the researcher developed an e-module as a more engaging and interactive learning medium. This e-module was designed to present physics formulas and materials in a more understandable way, which is expected to increase students' interest and ability in performing calculations. In addition to ineffective learning methods, teaching materials used in schools are still limited to print media. This hinders students from exploring and understanding the material in depth. Therefore, the e-modules developed by researchers are designed to present material in an engaging visual format that is relevant to everyday life, thereby increasing student enthusiasm for learning. These e-modules are also

flexible, as they can be accessed anytime and anywhere via electronic devices such as mobile phones or laptops. This provides students with greater opportunities for independent and interactive learning outside of class hours.

The curriculum used at this junior high school is the Independent Curriculum, including science lessons. However, in practice, this curriculum has not been fully implemented by educators, resulting in less than optimal classroom learning effectiveness. Natural Sciences (IPA) is a science derived from observations of nature and the various phenomena that occur within it. Science learning is integrated with various disciplines, both within the natural sciences themselves and other relevant disciplines. Besides being a scientific study, science also serves as a means of developing a scientific mindset (a way of thinking) (Park et al., 2020). Through an integrated learning approach, several relevant concepts can serve as central themes without the need for repeated discussion in different subject areas. This allows for more efficient use of learning time, as the material is presented in an integrated manner. Thus, the achievement of learning objectives is expected to be more effective, as students gain a comprehensive and meaningful understanding of the concepts being studied (Tong et al., 2022; Kumpas-Lenk et al., 2018).

The learning model implemented by educators tends to make students passive in the learning process. Learning remains teacher-centered, with the teacher dominating learning activities while students simply listen without responding or responding to the material presented (Bhardwaj et al., 2025; Zhou & Zhang, 2025). As a result, students struggle to reason deeply about the material being studied and are unable to conclude the main points of the material at the end of the lesson. This situation certainly hinders the development of students' critical thinking skills and conceptual understanding. Educators have not optimally applied educational technology through the use of innovative learning media (Souza & Debs, 2024). The learning process is still dominated by printed textbooks, which makes the classroom atmosphere monotonous and unengaging for students. This situation can result in low interest in learning and limited development of critical thinking skills.

Therefore, educators are required to provide engaging, interactive, and contextual learning media to increase student enthusiasm for learning and hone critical thinking skills. One innovative medium considered capable of igniting student enthusiasm for learning is the e-module. E-modules are attractively presented, systematically structured, and designed to facilitate understanding. Furthermore, e-modules can be accessed anytime and anywhere via electronic devices, significantly supporting learning flexibility. Therefore, researchers developed and implemented e-module learning media as a solution to the problem identified at SMPN 6 Padang Panjang, namely the limited use of varied and interactive learning media in the learning process.

Method

This study used the Research and Development (R&D) method with the ADDIE model to create a science e-module for eighth-grade students at SMPN 6 Padang Panjang. The goal was to produce a suitable and effective learning medium.

Research Stages

Analysis

The researcher conducted interviews with science teachers and observations in eighth-grade classrooms. The goal was to identify problems, student needs, and the condition of existing learning media.

Design

At this stage, the researcher designed the e-module framework. Activities included: Collecting science reference materials on substance pressure; Compiling materials, determining core competencies, and designing evaluations; Determining the title and design of the e-module.

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Development

The e-module design was validated by material, media, language, and subject teachers.

Validation used a Likert scale

Reliability testing was conducted using Cronbach's Alpha, with the instrument considered reliable if the value is >0.60.

Implementation

The e-module was trialed on a limited basis with 15 randomly selected eighth-grade students (low, medium, and high). The goal was to assess the initial effectiveness and student response to the e-module.

Evaluation

This stage involved a field trial involving all eighth-grade students and science teachers. Data was obtained from teacher and student questionnaire responses to improve the e-module. To test the effectiveness of the e-module, a one-group pretest-posttest design was used. The test results (pretest and posttest) were compared to determine whether the e-module was effective in improving students' learning outcomes and critical thinking skills.

Result and Discussion

This research resulted in a product in the form of an e-module for science subjects, developed based on the problems currently faced by students. This e-module allows students to access learning materials without time constraints, either via computer or mobile device. The main objective of this product development is to simplify the learning process and improve the skills of eighth-grade students at SMPN 6 Padang Panjang, particularly in understanding the topic of substance pressure. Based on interviews with science teachers, it was discovered that learning still uses conventional modules. This is due to teachers' limited ability to develop technology-based teaching materials, so they prefer to use readily available and easily applicable media, such as learning videos from YouTube. Furthermore, science lessons have not integrated critical thinking skills due to time constraints, so teachers tend to use practical, teacher-centered learning approaches. Consequently, students tend to be passive in the learning process and experience difficulty understanding physics concepts, particularly in the topic of substance pressure.

Based on daily assessment data, it was found that several students scored below the Minimum Completion Criteria (KKM). This demonstrates the need for innovation in learning media, one of which is through the development of Project-Based Learning (PjBL)-based e-modules designed to increase student active engagement and foster critical thinking skills. Students often experience difficulty understanding Natural Science (IPA) learning materials, particularly on the topic of substance pressure. This difficulty is caused by limited available knowledge sources and a lack of innovative methods used by educators in conveying information. However, the topic of substance pressure requires a learning approach that fosters conceptual understanding and develops students' critical thinking skills. Therefore, innovation is needed in the form of electronic-based learning materials (e-modules) that are flexible and engaging. E-modules enable students to study independently anytime and anywhere, whether through computers or mobile devices.

To address this issue, researchers designed an initial product in the form of an e-module as a learning medium that adheres to the Independent Curriculum. This e-module was systematically developed and includes several important components, including: cover, table of contents, learning outcomes, learning objectives, main material, supporting illustrations, and assignments that encourage active student involvement. The development phase began with the creation of the e-module as the initial product. This e-module was designed using the Canva platform to create an attractive and interactive display. Before the e-module was implemented in the learning process with students, a validation test was conducted to ensure the quality and appropriateness of the module's content. The validation process was conducted by four experts: a material expert, a media expert, a linguist, and an education expert (educator). This validation aimed to assess the extent to which the e-module met the e-module's eligibility standards in various aspects. Validity was assessed using the average percentage score for each aspect and the overall average percentage score.

The validation by material experts covers several important aspects, namely: Suitability of the material with learning outcomes, Accuracy of the material, Presentation techniques, Completeness and quality of presentation support (such as images and illustrations), Clarity of delivery, Communicative level of module content, Suitability of the use of good and correct Indonesian language rules, Suitability with the stages of the Project Based Learning (PjBL) learning model. The results of validation by material experts on the e-module are presented in Table 1.

Table 1. Results of Material Expert Validation

Assessment Aspects	Rating Scale
Suitability of Material to Learning Outcomes	8
Material Accuracy	12
Presentation Techniques	4
Presentation Support	16
Clearness	12
Communicativeness	4
Suitability to Language Rules	8
Suitability to PjBL Model Stages	32
Total	92
Percentage	80% (valid)

The validation results of the e-module by material experts showed that the product achieved a validity level of 80%, which falls into the "valid" category across all assessment aspects. This indicates that the material presented in the e-module aligns with the learning outcomes, is accurate, and is structured using presentation techniques that support project-based learning (Sánchez-García & Reyes-de-Cózar, 2025). Next, validation by linguists covered several linguistic aspects: language clarity, content communicativeness, dialogic and interactive engagement, appropriate use of Indonesian language rules, coherence and consistency of thought flow, and accuracy in the use of terms, symbols, or icons. The results of the linguist validation of the e-module are presented in Table 2.

The validation results of the e-module by a linguist showed a validity level of 62.23%, which falls into the "fairly valid" category. Based on these results, the linguist provided input for corrections to several sections containing typos to improve the linguistic

quality and readability of the e-module's content. Next, validation was conducted by a media expert who assessed the e-module's appearance and technical feasibility (Marheni et al., 2024). Aspects assessed included: e-module cover design, e-module content design, and ease of use. The results of the media expert validation are shown in Table 3.

Table 2. Results of Validation by Linguists

Assessment Aspects	Rating Scale
Straightforward	7
Communicative	11
Dialogic and Interactive	6
Suitability to Student Developmental Level	9
Coherence and Coherence of Thought Process	16
Use of Terms, Symbols, or Icons	12
Total	58
Percentage	62.23% (quite valid)

Table 3. Media Expert Validation Results

Assessment Aspects	Rating Scale
E-Module Cover Design	25
E-Module Content Design	25
Ease of Use	8
Total	58
Percentage	82.85% (valid)

Validation results by media experts showed that the e-module achieved a validity level of 82.85%, which falls into the "valid" category. This indicates that the visual design and layout of the e-module were deemed attractive, informative, and easy for students to use. Components such as cover design, content layout, and accessibility met the e-learning media eligibility standards (Risniawati et al., 2020; Azairok & Fathurohman, 2023). The complete results of the media expert validation are shown in Table 3. Next, validation was conducted by education experts, who assessed the e-module on various aspects directly related to learning implementation. These aspects include: content quality, language, e-module appearance, technical quality, and suitability to the PjBL stages. The results of the education expert validation are shown in Table 4.

Table 4. Results of Education Expert Validation

Assessment Aspects	Rating Scale
Content Quality	26
Language Quality	9
E-Module Appearance	18
Technical Quality	18
Suitability to PjBL Stages	35
Total	106
Percentage	88.33% (valid)

The validation results for the e-module conducted by educational experts yielded a score of 88.33%, which falls into the "Valid" category. This assessment indicates that the e-module is suitable for use as a teaching material (Abdullah et al., 2024; Purnamasari et al., 2024). Instrument validity testing was conducted using Microsoft Excel, using an inter-item correlation technique. The results of the validity test for each question item are presented in Table 5.

Table 5. Question Item Validity Results

Criteria	Question Number
Valid	1,2,3,4,5,6,7,8,9,10

The validity test for the descriptive questions was conducted using Microsoft Excel. Ten descriptive questions were administered to students. The results showed that all items met the validity criteria, making them suitable for measuring student abilities in accordance with the learning objectives (Vlachopoulos & Makri, 2024; Awaludin et al., 2024). Next, the Cronbach's Alpha technique was used to test the instrument's reliability. This test was conducted by distributing the questionnaire to students after it had been validated by experts. The results of the Cronbach's Alpha reliability test are shown in Table 6.

Table 6. Reliability Test Results

Reliability Coefficient	Interpretation
0.69	Reliable

The reliability test results showed a Cronbach's alpha value of 0.691304. The variable was proven reliable if the Cronbach's alpha value was >0.60. Based on the reliability test, it was concluded that the variables administered to students were reliable. Expert validation results indicated that the e-module designed and developed in this study was suitable for implementation in grade VIII of SMPN 6 Padang Panjang, however, several aspects needed to be improved. The e-module was implemented with students, beginning with a pre-test and ending with a post-test. The implementation aimed to determine the e-module's suitability for the learning process (Putra et al., 2023; Harahap et al., 2024). The pre-test and post-test were distributed directly in class. The implementation process in this study used a project-based learning (PjBL) model in accordance with the teaching module that had been developed (Heriansyah, 2020; Sutaryani et al., 2024), along with pre-test and post-test questions that had been validated by experts. The implementation stage in e-module development was carried out by piloting the teaching materials with grade VIII students of SMPN 6 Padang Panjang. This trial was conducted on

a limited basis, involving one educator and 15 students as research subjects.

Table 7. Pre-test and Post-test Results

Description	Pre-test	Post-test
Max score	77	92
Min score	56	80
Average	68.36	85.16

This phase began with a pre-test administered to all students before they received and used the e-module. The pre-test aimed to measure students' initial understanding of the learning material before the intervention. Next, the learning activities continued with the application of the e-module as the main teaching material during the learning process. The e-module was used directly by students in classroom learning activities, according to a learning scenario developed based on the Project-Based Learning (PjBL) model (Li & Tu, 2024; Doyan et al., 2024). After completing the e-module learning, students were given a post-test. This post-test aimed to measure students' understanding after using the e-module and to assess the success and effectiveness of the e-module as a development product. The results of the students' pre-test and post-test scores are shown in Table 7.

Based on the results of the pre-test and post-test conducted by the students, the data obtained is as shown in Table 7. The average pre-test score obtained by students was 68.36, with a minimum score of 56 and a maximum score of 77. Meanwhile, the average post-test score increased to 85.16, with a minimum score of 80 and a maximum score of 92. From these results, it can be concluded that there was an increase in student scores after using the e-module as a teaching material (Dini et al., 2023). This indicates that the developed e-module made a positive contribution to student understanding of the material. To determine whether the pre-test and post-test data were normally distributed, a normality test was conducted using the SPSS application using the One-Sample Kolmogorov-Smirnov Test (Aini et al., 2020; Pirdayanti et al., 2022). This test aims to ensure that the data meets the assumptions of a normal distribution, which is important in determining the next steps in the statistical analysis. The results of the normality test using the One-Sample Kolmogorov-Smirnov Test are presented in Table 8.

Table 8. Normality Test Results

		Tests of Normality					
		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Class	Statistic	df	Sig.	Statistic	df	Sig.
Result	Pretest	.134	25	.200*	.935	25	.111
	Posttest	.131	25	.200*	.941	25	.155

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

Table 9. Paired t-Test Results

Paired samples Test										
		Paired differences								
		Mean	Std. Deviation	Std. Error Mean	95% Confidence intervalof the difference		t	df	Sig(2-tiled)
					Lower	Upper			
Pair 1	Pre-test -Post- test	-16.800	-7.83	1.56	-20.033	-13.56	-10.72	24	.000

A normality test was conducted to determine whether the pre-test and post-test data were normally distributed. This test used the One-Sample Kolmogorov-Smirnov Test using the SPSS application. The test results showed a significance value (sig.) for the pre-test data of 0.200, and for the post-test data of 0.200. Because the significance values for both data sets were greater than 0.05, it can be concluded that the pre-test and post-test data were normally distributed. Therefore, the data met the requirements for parametric testing, one of which is the paired t-test (Rietveld & Van Hout, 2017; Abdi, 2023). After the data were determined to be normally distributed, a hypothesis test was conducted using the Paired Sample t-test method. This test aimed to determine whether there was a significant difference between the pre-test and post-test results after the implementation of the e-module as a learning medium. This study used a single class as a sample, with a total of 15 students. The paired t-test was conducted on two sets of paired data: the pre-test and post-test scores from the same students. The paired t-test analysis results showed a significant difference between the pre-test and post-test scores, indicating that the implementation of the e-module had a positive impact on improving student understanding (Yani et al., 2024). The complete results of the paired t-test are presented in Table 9. Based on the

table 9 in the Paired Samples Test table, it is known that the Sig.(2-tailed) value is 0.000 < 0.05, so Ho is rejected and Ha is accepted.

Conclusion

Development: This e-module is designed using the ADDIE model and integrates the stages of PjBL to encourage students to think critically, creatively, and actively; Feasibility: The e-module is considered highly feasible based on several aspects, namely: Content: The material is engaging and supported by illustrations that facilitate understanding.; Learning Objectives: The activities align with the expected core competencies.; Language: The language used is simple and easy for students to understand.; Function: The e-module encourages active participation and independence in student learning; Effectiveness: Post-test results show improved learning outcomes after using the e-module. This demonstrates that this e-module has the potential to enhance students' critical thinking skills through projects that stimulate analysis and problem-solving.

Acknowledgments
Thank you to all parties who have supported this research. We hope this research proves beneficial.

Author Contributions
Conceptualization, methodology, validation, formal analysis, investigation, resources, S. A. Y., Y; data curation, preparation of the initial draft of the manuscript, review and editing of the manuscript, visualization, Y. All authors have read and approved the published version of the manuscript.

Funding
The researchers independently funded this research.

Conflicts of Interest
The authors declare no conflict of interest.

References

Abdi, S. J. (2023). A Comprehensive Guide for Selecting Appropriate Statistical Tests: Understanding When to Use Parametric and Nonparametric Tests. *Open Journal of Statistics*, *13*(04), 464–474. https://doi.org/10.4236/ojs.2023.134023

Abdullah, Herdini, & Putri, T. S. (2024). Validity and Practicality of E-Module Based on Phenomenon Based Learning Using Articulate Storyline on Material Colligative Properties of Solutions. *Jurnal Penelitian Pendidikan IPA*, *10*(2), 764–775. https://doi.org/10.29303/jppipa.v10i2.5837

Abdulrahaman, M. D., Faruk, N., Oloyede, A. A., Surajudeen-Bakinde, N. T., Olawoyin, L. A., Mejabi, O. V., Imam-Fulani, Y. O., Fahm, A. O., & Azeez, A. L. (2020). Multimedia tools in the teaching and learning processes: A systematic review. *Heliyon*, *6*(11), e05312. https://doi.org/10.1016/j.heliyon.2020.e05312

Aini, K., Hobri, Prihandoko, A. C., Yuniar, D., Faozi, A. K. A., & Asmoni. (2020). The students' mathematical communication skill on caring community-based learning cycle 5E. *Journal of Physics: Conference Series*, *1538*(1), 012075. https://doi.org/10.1088/1742-6596/1538/1/012075

Anjani, F., Fatmawati, U., & Ariyanto, J. (2024). Development e-module on genetic materials to enhance student's critical thinking skills. *Biosfer*, *17*(1), 32–44. https://doi.org/10.21009/biosferjpb.29539

Awaludin, A., Ruhiat, Y., Anriani, N., & Suryadi, S. (2024). The Effect of Learning Method and Self-Confidence on Student Learning Outcomes. *IJORER: International Journal of Recent Educational Research*, *5*(3), 733–747. https://doi.org/10.46245/ijorer.v5i3.604

Azairok, M., & Fathurohman, A. (2023). Development of E-Learning Based Learning Media Assisted by Chamilo in Learning Physics to Improve Learning Outcomes of High School Students. *Jurnal Penelitian Pendidikan IPA*, *9*(10), 7871–7878. https://doi.org/10.29303/jppipa.v9i10.4594

Bhardwaj, V., Zhang, S., Tan, Y. Q., & Pandey, V. (2025). Redefining learning: Student-centered strategies for academic and personal growth. *Frontiers in Education*, *10*, 1518602. https://doi.org/10.3389/feduc.2025.1518602

Blanka, C., Krumay, B., & Rueckel, D. (2022). The interplay of digital transformation and employee competency: A design science approach. *Technological Forecasting and Social Change*, *178*, 121575. https://doi.org/10.1016/j.techfore.2022.121575

Dini, A., Rahmatan, H., Muhibbudin, Nurmaliah, C., & Safrida. (2023). Application of the E-module combined with the Guided Inquiry Learning Model to Increase Student Motivation and Learning Outcomes on the Structure and Function of Plant Tissues. *Jurnal Penelitian Pendidikan IPA*, *9*(6), 4768–4776. https://doi.org/10.29303/jppipa.v9i6.3857

Doyan, A., Harjono, A., & Qadafi, M. (2024). Trends Research Project Based Learning (PjBL) Model to Improve Problem Solving Skills in Students' Science Learning (2015-2024): A Systematic Review. *Jurnal Penelitian Pendidikan IPA*, *10*(7), 498–507. https://doi.org/10.29303/jppipa.v10i7.8280

Golden, B. (2023). Enabling critical thinking development in higher education through the use of a structured planning tool. *Irish Educational*

Studies, *42*(4), 949–969. https://doi.org/10.1080/03323315.2023.2258497

Haleem, A., Javaid, M., Qadri, M. A., & Suman, R. (2022). Understanding the role of digital technologies in education: A review. *Sustainable Operations and Computers*, *3*, 275–285. https://doi.org/10.1016/j.susoc.2022.05.004

Harahap, N. I., Hakim, R., Rayendra, & Ridwan. (2024). Development of Physics Learning E-Module for Class X High School Students. *Jurnal Penelitian Pendidikan IPA*, *10*(7), 3689–3696. https://doi.org/10.29303/jppipa.v10i7.7548

Heriansyah, M. (2020). Proactivity inventory development for senior high school students. *JPPI (Jurnal Penelitian Pendidikan Indonesia)*, *6*(1), 27–30. https://doi.org/10.29210/02020344

Herlinawati, H., Marwa, M., Ismail, N., Junaidi, Liza, L. O., & Situmorang, D. D. B. (2024). The integration of 21st century skills in the curriculum of education. *Heliyon*, *10*(15), e35148. https://doi.org/10.1016/j.heliyon.2024.e35148

Horváth, D., & Szabó, R. Zs. (2019). Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities? *Technological Forecasting and Social Change*, *146*, 119–132. https://doi.org/10.1016/j.techfore.2019.05.021

Javaid, M., Haleem, A., Singh, R. P., & Sinha, A. K. (2024). Digital economy to improve the culture of industry 4.0: A study on features, implementation and challenges. *Green Technologies and Sustainability*, *2*(2), 100083. https://doi.org/10.1016/j.grets.2024.100083

Khotimah, N., Pamuji, & Astawan, I. G. (2024). The Effectiveness of Early Science and Mathematics Development E-Modules to Improve Early Childhood Concept Understanding. *Mimbar Ilmu*, *29*(2), 343–349. https://doi.org/10.23887/mi.v29i2.84541

Kraus, S., Jones, P., Kailer, N., Weinmann, A., Chaparro-Banegas, N., & Roig-Tierno, N. (2021). Digital Transformation: An Overview of the Current State of the Art of Research. *Sage Open*, *11*(3), 21582440211047576. https://doi.org/10.1177/21582440211047576

Kumpas-Lenk, K., Eisenschmidt, E., & Veispak, A. (2018). Does the design of learning outcomes matter from students' perspective? *Studies in Educational Evaluation*, *59*, 179–186. https://doi.org/10.1016/j.stueduc.2018.07.008

Li, M.-M., & Tu, C.-C. (2024). Developing a Project-Based Learning Course Model Combined with the Think–Pair–Share Strategy to Enhance Creative Thinking Skills in Education Students. *Education Sciences*, *14*(3), 233. https://doi.org/10.3390/educsci14030233

Luh Gede Sutaryani, Ni Made Pujani, & I Nyoman Tika. (2024). Project-Based Learning on Science Process Skills and Learning Outcomes in High School Physics: A Quasi-Experimental Study on the Topic of Fluids. *Journal of Education Research and Evaluation*, *8*(4), 806–815. https://doi.org/10.23887/jere.v8i4.83769

Marheni, K. R., Suarjana, I. M., & Paramita, M. V. A. (2024). Interactive E-Module on Perimeter and Area of Plane Figures Based on Balinese Ethnomathematics to Enhance the Creativity Skills. *MIMBAR PGSD Undiksha*, *12*(3), 413–424. https://doi.org/10.23887/jjpgsd.v12i3.91783

Park, W., Wu, J.-Y., & Erduran, S. (2020). The Nature of STEM Disciplines in the Science Education Standards Documents from the USA, Korea and Taiwan: Focusing on Disciplinary Aims, Values and Practices. *Science & Education*, *29*(4), 899–927. https://doi.org/10.1007/s11191-020-00139-1

Pirdayanti, N. P. A., Nitiasih, P. K., Budiarta, L. G. R., & Adnyayanti, N. L. P. E. (2022). The Impact of Videos Based Discovery Learning Towards Young Learners' Speaking Skill During Pandemic Covid-19. *Jurnal Pedagogi Dan Pembelajaran*, *5*(2), 285–292. https://doi.org/10.23887/jp2.v5i2.45556

Purnamasari, E. F., Maasawet, E. T., Hudiyono, Y., Subagiyo, L., Herliani, & Akhmad. (2024). Effectiveness of Biology E-Module Teaching Materials Based on Flip Pdf Professional Application to Improve Learning Outcomes and Critical Thinking Skills. *Jurnal Penelitian Pendidikan IPA*, *10*(11), 8892–8898. https://doi.org/10.29303/jppipa.v10i11.9147

Putra, A. W., Lamangantjo, C. J., & Uloli, R. (2023). E-Module Development Using the Canva Application on Environmental Pollution Concept. *Jurnal Penelitian Pendidikan IPA*, *10*(7), 4010–4018. https://doi.org/10.29303/jppipa.v10i7.7790

Rasyih, H., Noer, A. M., & Rasmiwetti, R. (2024). Pengembangan E-Modul Berbasis Social Scientific Issue (Ssi) Untuk Meningkatkan Kemampuan Berpikir Kritis Dan Enviromental Care Pada Materi Kimia Hijau Di Kelas X SMA Dengan Menggunakan Aplikasi Fliphtml5. *Jurnal Penelitian Pendidikan IPA*, *10*(8), 6059–6069. https://doi.org/10.29303/jppipa.v10i8.8102

Rehman, N., Huang, X., Mahmood, A., AlGerafi, M. A. M., & Javed, S. (2024). Project-based learning as a catalyst for 21st-Century skills and student engagement in the math classroom. *Heliyon*, *10*(23), e39988. https://doi.org/10.1016/j.heliyon.2024.e39988

Rietveld, T., & Van Hout, R. (2017). The paired t test and beyond: Recommendations for testing the central tendencies of two paired samples in research on speech, language and hearing pathology. *Journal of Communication Disorders*, *69*, 44–57. https://doi.org/10.1016/j.jcomdis.2017.07.002

Risniawati, M., Serevina, V., & Delina, M. (2020). The development of E-learning media to improve students' science literacy skill in Senior High School. *Journal of Physics: Conference Series*, *1481*, 012075. https://doi.org/10.1088/1742-6596/1481/1/012075

Sánchez-García, R., & Reyes-de-Cózar, S. (2025). Enhancing Project-Based Learning: A Framework for Optimizing Structural Design and Implementation—A Systematic Review with a Sustainable Focus. *Sustainability*, *17*(11), 4978. https://doi.org/10.3390/su17114978

Selano, Y. P., Sutimin, L. A., & Sumaryati, S. (2024). Web-Based E-Module with a Project Based Learning Approach to Improve Computational Thinking Skills of High School Students. *Journal of Education Technology*, *8*(4), 763–775. https://doi.org/10.23887/jet.v8i4.85248

Sivasankari, N., & Rathika, P. (2025). IoT driven building automation systems: A review on energy efficiency, occupant comfort, and sustainability. *Journal of Building Engineering*, *104*, 112347. https://doi.org/10.1016/j.jobe.2025.112347

Souza, A. S. C. D., & Debs, L. (2024). Concepts, innovative technologies, learning approaches and trend topics in education 4.0: A scoping literature review. *Social Sciences & Humanities Open*, *9*, 100902. https://doi.org/10.1016/j.ssaho.2024.100902

Tong, D. H., Uyen, B. P., & Ngan, L. K. (2022). The effectiveness of blended learning on students' academic achievement, self-study skills and learning attitudes: A quasi-experiment study in teaching the conventions for coordinates in the plane. *Heliyon*, *8*(12), e12657. https://doi.org/10.1016/j.heliyon.2022.e12657

Vlachopoulos, D., & Makri, A. (2024). A systematic literature review on authentic assessment in higher education: Best practices for the development of 21st century skills, and policy considerations. *Studies in Educational Evaluation*, *83*, 101425. https://doi.org/10.1016/j.stueduc.2024.101425

Yani, N. L. S., Rusdarti, & Oktarina, N. (2024). STEM-Based E-Modules to Improve Students' Critical Thinking in Economic Learning. *Thinking Skills and Creativity Journal*, *7*(1), 115–121. https://doi.org/10.23887/tscj.v7i1.73518

Zhou, Q., & Zhang, H. (2025). Flipped Classroom Teaching and ARCS Motivation Model: Impact on College Students' Deep Learning. *Education Sciences*, *15*(4), 517. https://doi.org/10.3390/educsci15040517