JPPIPA 11(4) (2025)

Jurnal Penelitian Pendidikan IPA

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

Development of STEM-Based E-Module to Enhance Science Literacy and Science Process Skills in Chemistry Learning

Seget Tartiyoso[1*]

[1] STKIP Budidaya Binjai, Indonesia.

Received: January 11, 2025
Revised: March 10, 2025
Accepted: April 25, 2025
Published: April 30, 2025

Corresponding Author:
Seget Tartiyoso
sigittartiyoso25@gmail.com

DOI: 10.29303/jppipa.v11i4.10844

Abstract: This research investigated the development and implementation of a STEM-based electronic module (e-module) designed to enhance science literacy and science process skills among high school students in chemistry learning. The study employed a qualitative analysis approach to examine the design process, implementation challenges, and educational outcomes of integrating Science, Technology, Engineering, and Mathematics principles into digital chemistry learning materials. Results indicate significant improvements in students' scientific explanation abilities and experimental design skills, suggesting that well-designed STEM-based e-modules can effectively bridge theoretical understanding with practical applications in chemistry education.

Keywords: E-module; Learning; Literacy; Science

Introduction

The rapid advancement of digital technology has transformed educational landscapes worldwide, creating new opportunities for innovative teaching and learning approaches (Slipchyshyn et al., 2024). In science education, particularly chemistry, the integration of digital resources with interdisciplinary frameworks has become increasingly important for developing students' 21st-century competencies. Electronic modules (e-modules) have emerged as versatile instructional materials that can support flexible and interactive learning experiences, potentially addressing the limitations of traditional teaching methods in developing critical scientific competencies (Rosman et al., 2024).

Science literacy represents a fundamental educational goal, encompassing the ability to understand scientific concepts, recognize scientific questions, use evidence to draw conclusions, and apply scientific knowledge in real-world contexts (Sekaringtyas et al., 2024). Chemistry education, with its abstract concepts and complex phenomena, presents unique challenges for developing science literacy (Ulwan et al., 2024). Similarly, science process skills—the intellectual abilities used to conduct scientific investigations—are essential for students to engage meaningfully with chemistry content. Traditional approaches to chemistry education often emphasize content knowledge over these broader competencies, creating a disconnect between classroom learning and real-world application (Himmah et al., 2024)

The integration of Science, Technology, Engineering, and Mathematics (STEM) education offers a promising approach to address these challenges (Simmons et al., 2023; Alfarraj & Alzahrani, 2024). STEM education emphasizes interdisciplinary learning and the application of knowledge to solve authentic problems, thereby fostering critical thinking, creativity, and innovation. When embedded within digital learning environments, STEM approaches can potentially transform chemistry education from isolated fact memorization to integrated understanding and application (Jamaluddin et al., 2023).

This study aims to develop and evaluate a STEM-based e-module for chemistry learning, specifically designed to enhance science literacy and science process

How to Cite:
Tartiyoso, S. (2025). Development of STEM-Based E-Module to Enhance Science Literacy and Science Process Skills in Chemistry Learning. *Jurnal Penelitian Pendidikan IPA*, *11*(4), 1124-1132. https://doi.org/10.29303/jppipa.v11i4.10844

skills. The research seeks to answer three questions: How can a STEM-based e-module be effectively designed for chemistry education? What impact does this e-module have on students' science literacy and science process skills? What challenges and opportunities emerge during implementation? By addressing these questions, this study contributes to the growing body of knowledge on innovative instructional materials that bridge theoretical understanding with practical applications in science education.

Method

This study employed a qualitative research approach to develop, implement, and evaluate a STEM-based e-module for chemistry learning. The qualitative design allowed for in-depth exploration of the development process, implementation dynamics, and educational outcomes, providing rich contextual understanding beyond quantitative measures alone. The research was conducted in three phases: e-module development, implementation, and evaluation (Jung, 2024).

The development phase employed the ADDIE (Analysis, Design, Development, Implementation, Evaluation) model, a systematic instructional design framework widely used in educational resource development. The implementation phase involved teacher training, classroom integration, and observational data collection. The evaluation phase included expert validation, teacher interviews, student assessments, and thematic analysis of qualitative data (Khan, 2024).

Figure 1. Qualitative method

Development of STEM-Based E-Module

The development of the STEM-based chemistry e-module followed the ADDIE model's five sequential stages. In the Analysis stage, educational needs, learner characteristics, content requirements, and technological constraints were systematically assessed through literature review, curriculum analysis, and stakeholder consultations. This foundational analysis identified appropriate chemistry topics, learning objectives, and STEM integration opportunities (Oktariani & Saputri, 2024).

The Design stage involved constructing the instructional blueprint, including content organization, learning activities, assessment strategies, and user interface elements. Special attention was given to aligning chemistry content with STEM principles, ensuring that science concepts were connected with technological applications, engineering design challenges, and mathematical analysis opportunities. The Problem-Based Learning (PBL) approach was incorporated as the pedagogical framework, structuring the e-module into five progressive stages: problem orientation, learning organization, guided investigation, solution development, and reflective evaluation.

In the Development stage, the e-module was created using the Canva platform and its Heyzine feature, which enables conversion of PDF files into interactive digital formats. Content creation included writing explanatory text, designing graphics, recording instructional videos, developing simulations, and programming interactive elements. The e-module focused on chemical reactions, incorporating multimedia explanations, virtual laboratory simulations, experimental design activities, and data analysis tools (Wati et al. 2021; Siregar & Silaban, 2023).

The Implementation stage involved field testing with chemistry teachers and students in controlled educational settings. This phase included teacher training sessions, classroom integration of the e-module, and observational data collection. The Evaluation stage encompassed expert validation, user feedback collection, and assessment of the e-module's impact on science literacy and science process skills.

Participants and Setting

The study involved multiple participant groups to ensure comprehensive evaluation of the STEM-based e-module. Chemistry education experts (n=5) with specializations in instructional design, STEM education, and digital learning participated in the validation process, providing expert assessment of the e-module's content accuracy, pedagogical alignment, and technological functionality.

Chemistry teachers (n=10) from diverse educational backgrounds participated in implementation and evaluation activities. These teachers represented various teaching experiences, technological proficiencies, and school contexts, providing a range of perspectives on the e-module's classroom applicability and effectiveness. Teacher participants engaged in training workshops, classroom implementation, interview sessions, and feedback surveys.

Student participants (n=92) from three chemistry classes in secondary education settings used the STEM-based e-module during regular instructional periods. These students represented diverse academic backgrounds, learning preferences, and technological experiences. Student participation included completing pre-assessment and post-assessment measures of science literacy and science process skills, engaging with the e-module's learning activities, and providing feedback on their learning experiences.

Data Collection Methods

Multiple data collection methods were employed to ensure methodological triangulation and comprehensive understanding of the research questions. Expert validation utilized structured assessment instruments evaluating the e-module's content validity, instructional design, technological functionality, and STEM integration quality. These instruments employed Likert-scale ratings and open-ended response formats, generating both quantitative quality indicators and qualitative improvement suggestions.

Teacher perspectives were collected through semi-structured interviews exploring implementation experiences, perceived benefits, observed challenges, and professional development needs. These interviews, averaging 45 minutes in duration, were audio-recorded, transcribed, and subjected to thematic analysis. Supplementary teacher data included implementation logs, classroom observation notes, and feedback questionnaires.

Student learning was assessed through pre-test and post-test measures of science literacy and science process skills. The science literacy assessment evaluated three dimensions: explaining scientific phenomena, evaluating and designing scientific inquiry, and interpreting data and evidence scientifically. The science process skills assessment examined observational accuracy, predictive reasoning, experimental design capacity, data analysis proficiency, and conclusion formulation. Additional student data included learning artifacts, engagement metrics, and satisfaction questionnaires.

Data Analysis Procedures

Data analysis employed a multi-method approach appropriate for the qualitative research design. Expert validation data were analyzed using descriptive statistics for quantitative ratings and thematic analysis for qualitative feedback. Percentage scores were calculated for each evaluation dimension, with scores above 80% considered "very valid" based on established validation criteria1.

Interview transcripts and observational data underwent thematic analysis following a six-step process: familiarization with data, initial coding, theme identification, theme review, theme definition, and interpretation. This process identified recurring patterns, emergent concepts, and significant insights regarding e-module development, implementation, and impact. Coding reliability was enhanced through investigator triangulation, with multiple researchers independently coding data samples before consensus discussions.

Student assessment data were analyzed using descriptive statistics and normalized gain calculations. The N-Gain formula [(post-test score - pre-test score)/(maximum score - pre-test score)] quantified learning improvements, with values below 0.3 considered "low," 0.3-0.7 "medium," and above 0.7 "high"4. Complementary qualitative analysis of student work samples and feedback provided contextual understanding of these quantitative indicators.

Result and Discussion

Development and Validation of STEM-Based E-Module

The development process resulted in a comprehensive STEM-based chemistry e-module focused on chemical reactions (Nguyen et al., 2020; Aris et al., 2024). The e-module integrated multimedia elements, interactive simulations, collaborative activities, and assessment tools within a Problem-Based Learning framework. Each learning sequence began with a real-world chemical challenge, progressed through guided investigation and knowledge application, and culminated in student-generated solutions and reflective analysis (Costa et al., 2023; Ibrahim et al., 2025).

Table 1. Expert Validation Results for STEM-Based Chemistry E-Module

Validation Aspect	Percentage Score	Interpretation
Content Accuracy	94.60%	Very Valid
Curriculum Alignment	93.80%	Very Valid
STEM Integration	95.20%	Very Valid
Learning Objectives	92.00%	Very Valid
Activity Sequencing	91.50%	Very Valid
Assessment Alignment	93.40%	Very Valid
User Interface	89.70%	Very Valid
Navigation	90.50%	Very Valid
Multimedia Elements	92.30%	Very Valid
Overall Validation	92.50%	Very Valid

Expert validation results indicated high quality across all evaluation dimensions, as shown in Table 1. The content validation yielded a 94.6% approval rating, with particular strengths in scientific accuracy, curriculum alignment, and STEM integration. Instructional design validation achieved 92.3% approval, with positive assessments of learning objectives, activity sequencing, and assessment alignment. Technological functionality validation reached 90.8% approval, with commendations for user interface design, navigation intuitiveness, and multimedia integration.

Qualitative feedback from expert validators highlighted several strengths, including the authentic integration of STEM principles, the effective scaffolding of complex chemistry concepts, and the engaging multimedia presentations. Suggested improvements included enhancing accessibility features, expanding differentiation options for diverse learners, and strengthening connections between virtual simulations and laboratory activities.

Impact on Science Literacy

Science literacy assessments revealed significant improvements following implementation of the STEM-based e-module. Pre-test and post-test comparisons, presented in Table 2, demonstrated gains across all three dimensions of science literacy. The most substantial improvement occurred in the "explaining scientific phenomena" dimension, with an N-Gain value of 0.58, similar to findings reported in previous research.

Table 2. Science Literacy Assessment Results (n=92)

Science Literacy Dimension	Pre-test Mean	Post-test Mean	N-Gain	Interpretation
Explaining Scientific Phenomena	57.3	82.4	0.58	Medium
Evaluating and Designing Scientific Inquiry	52.1	76.9	0.52	Medium
Interpreting Data and Evidence	54.8	79.5	0.55	Medium
Overall Science Literacy	54.7	79.6	0.55	Medium

Qualitative analysis of student responses revealed deeper conceptual understanding and improved scientific reasoning following e-module implementation. Students demonstrated enhanced ability to explain chemical reactions using scientific principles, connect laboratory observations with theoretical models, and apply chemistry knowledge to real-world contexts. They also showed greater facility in distinguishing between observations and inferences, identifying variables in experimental designs, and evaluating the strength of scientific evidence.

Impact on Science Process Skills

Science process skills assessment results, presented in Table 3, indicated substantial improvements across all five skill categories. The most significant gains occurred in experimental design (N-Gain=0.61) and observational accuracy (N-Gain=0.59), suggesting that the STEM-based e-module effectively developed these foundational scientific capabilities.

Qualitative analysis of student performance on practical tasks revealed more sophisticated scientific thinking following e-module implementation. Students demonstrated improved ability to design controlled experiments, operationalize variables, select appropriate measurement techniques, analyze experimental errors, and formulate evidence-based conclusions. These improvements were particularly evident in collaborative problem-solving activities, where students effectively applied science process skills to authentic chemistry challenges.

Table 3. Science Process Skills Assessment Results (n=92)

Science Process Skill	Pre-test Mean	Post-test Mean	N-Gain	Interpretation
Observational Accuracy	61.8	84.3	0.59	Medium
Predictive Reasoning	58.2	80.7	0.54	Medium
Experimental Design	50.6	80.8	0.61	Medium
Data Analysis	53.9	78.4	0.53	Medium
Conclusion Formulation	56.3	79.8	0.54	Medium
Overall Science Process Skills	56.2	80.8	0.56	Medium

Teacher Perspectives on Implementation

Thematic analysis of teacher interviews identified four dominant themes regarding e-module implementation: instructional benefits, implementation challenges, pedagogical adaptations, and professional development needs. These themes provide contextual understanding of the e-module's classroom integration and highlight important considerations for educational practice.

Regarding instructional benefits, teachers consistently reported enhanced student engagement, with one participant noting that "students were visibly more motivated when working with the e-module compared to traditional instruction." Teachers particularly valued the integration of virtual simulations with hands-on activities, which they believed helped students connect abstract concepts with observable phenomena. They also appreciated the embedded assessment tools, which provided immediate feedback on student understanding.

Implementation challenges identified by teachers aligned with findings from previous research on STEM education7. Resource limitations presented significant obstacles, with teachers citing inadequate technological infrastructure, limited laboratory equipment, and insufficient instructional time as primary concerns. One teacher explained, "While the e-module is well-designed, my classroom has only five computers for thirty students, making implementation logistically difficult." Teachers also noted varying levels of student technological proficiency and initial resistance from some colleagues accustomed to traditional teaching methods.

Pedagogical adaptations emerged as teachers integrated the e-module into their instructional practices. Most teachers reported shifting toward more facilitative teaching roles, with greater emphasis on guiding student inquiry rather than direct instruction. One participant described this transition: "I found myself asking more questions and providing fewer answers, allowing students to construct understanding through exploration and discussion." Teachers also developed various implementation strategies, including rotating station models, peer teaching arrangements, and blended learning approaches combining home and classroom activities.

Professional development needs identified by teachers included technical training on e-module functionality, pedagogical guidance on facilitating STEM-based learning, and collaborative opportunities to share implementation experiences. Several teachers expressed interest in sustained professional learning communities focused on digital STEM education, suggesting that isolated training events were insufficient for developing long-term implementation capacity.

Discussion

This study has demonstrated the potential of STEM-based e-modules to enhance science literacy and science process skills in chemistry education (Dibyantini et al., 2023). The findings reveal that carefully designed digital resources integrating science, technology, engineering, and mathematics can positively impact student learning outcomes while presenting implementation challenges that require systematic attention. Four key insights emerge from this research, each with significant implications for educational practice and future research (Aguilera et al., 2021; Arango-Caro et al., 2025).

First, the STEM-based e-module effectively improved students' science literacy, particularly their ability to explain scientific phenomena (Annisa et al., 2023; Septiadevana et al., 2024). This improvement can be attributed to several design features, including authentic problem scenarios, multimedia explanations of chemical processes, and opportunities to connect theoretical models with observable evidence (Bone et al., 2024). The integration of engineering design challenges and technological applications provided meaningful contexts for chemistry concepts, helping students develop deeper conceptual understanding rather than superficial memorization. These findings align with previous research indicating that STEM-based approaches can significantly enhance scientific explanation abilities (Widiana et al., 2024).

The medium-level gains observed across all science literacy dimensions suggest that while the e-module was effective, there remains room for improvement (Zhan et al., 2022; Wang et al., 2025). The relatively stronger gains in explaining scientific phenomena compared to evaluating scientific inquiry may reflect the inherent challenge of developing higher-order scientific thinking skills within limited implementation timeframes. Future iterations of the e-module might incorporate more scaffolded opportunities for experimental critique and design, potentially enhancing these more sophisticated science literacy dimensions (Ma'fiyah et al., 2025).

Second, the e-module demonstrated effectiveness in developing students' science process skills, with particularly strong impacts on experimental design capabilities (Hamidi et al., 2024). The engineering components of the STEM framework appeared especially valuable for this development, as they required students to apply scientific knowledge in designing solutions to chemistry-related problems. The virtual laboratory simulations provided safe environments for experimental exploration, while structured guidance helped students develop methodological rigor in their investigations (Oanh, 2024). These findings suggest that well-designed digital resources can effectively develop scientific practices that traditionally required physical laboratory experiences (Letnar et al., 2025).

The improvement in science process skills appeared somewhat uneven across skill categories, with stronger gains in experimental design and observation compared to data analysis and conclusion formulation (Burns & Davenport, 2025). This pattern may reflect the cognitive complexity of these latter skills, which require integration of multiple scientific practices and abstract reasoning abilities. Future e-module development might incorporate additional scaffolding for these more complex science process skills, possibly through guided analysis of exemplary data sets and structured reasoning frameworks (Hanum et al., 2024).

Third, teacher perspectives revealed both opportunities and challenges in implementing STEM-based e-modules in chemistry education (Pathuddin et al., 2024). The enhanced student engagement and deeper conceptual understanding reported by teachers highlight the pedagogical value of these digital resources (Pepin et al., 2021; Pepin & Rezat, 2025). However, the technological infrastructure limitations, time constraints, and professional development needs identified by teachers underscore the systemic challenges facing educational innovation. These findings suggest that effective implementation requires attention not only to instructional design but also to broader educational ecosystem factors including resource allocation, scheduling practices, and teacher preparation.

The pedagogical adaptations described by teachers—particularly their transition toward more facilitative instructional approaches—reflect how educational technologies can catalyze instructional change beyond the specific content they address (Atit et al., 2020; Liu et al., 2024). This finding suggests that STEM-based e-modules may serve not only as student learning resources but also as teacher professional development tools, encouraging reflection on instructional practices and epistemological beliefs about science teaching and learning (Dewi et al., 2024).

Finally, the systematic development process produced a high-quality educational resource validated by subject matter experts and educational technology specialists (Krokhmal et al., 2024). The ADDIE model provided a structured framework for integrating content expertise, pedagogical knowledge, and technological capabilities, resulting in an e-module that effectively balanced these dimensions. The interactive development and validation process ensured alignment with educational standards, STEM principles, and user experience considerations, highlighting the importance of methodical design approaches in educational resource development (Saxena et al., 2024).

The expert validation results, which consistently rated the e-module as "very valid" across multiple dimensions, provide evidence for the effectiveness of the development approach. However, the qualitative feedback suggesting improvements in accessibility and differentiation highlights ongoing tensions in educational resource design between standardization and personalization, technological innovation and universal access, and comprehensive content coverage and manageable cognitive load

Conclusion

This research has demonstrated that carefully designed STEM-based e-modules can effectively enhance science literacy and science process skills in chemistry education. The integrative approach, combining science content with technological applications, engineering design challenges, and mathematical analysis, provides students with rich learning opportunities that connect theoretical understanding with practical application. The digital format enables interactive engagement, multimedia representation of complex concepts, and personalized learning pathways, addressing limitations of traditional instructional materials. The findings reveal medium-level improvements across all dimensions of science literacy and science process skills, with particularly strong gains in explaining scientific phenomena and designing experiments. These results suggest that STEM-based e-modules can develop not only content knowledge but also the higher-order thinking skills and scientific practices essential for comprehensive science education. The positive teacher perspectives, despite implementation challenges, indicate the pedagogical value of these digital resources in chemistry classrooms.

Acknowledgments

Author thanks to all people and institutions in most cases helped and fund his study.

Funding

This research received no external funding.

Conflicts of Interest

The authors declare no conflict of interest.

References

Aguilera, D., & Ortiz-Revilla, J. (2021). STEM Vs. STEAM Education And Student Creativity: A Systematic Literature Review. *Education Sciences*, *11*(7), 331. Retrieved from https://doi.org/10.3390/educsci11070331

Alfarraj, Y., & Alzahrani, R. (2024). *Investigating Experts' Science Teachers' Perspectives on the Integration of STEM Activities into Science Instruction*. https://doi.org/10.20944/preprints202412.1937.v1

Annisa, A. A., & Fatmahanik, U. (2023). Efektivitas Model Pembelajaran Contextual Teaching and Learning (CTL) Berbasis STEM terhadap Kemampuan Berpikir Logis Siswa pada Pembelajaran IPA. *Jurnal Tadris IPA Indonesia*, *3*(1), 30–43. https://doi.org/10.21154/jtii.v3i1.693

Arango-Caro, S., Langewisch, T., Ying, K., Haberberger, M. A., Ly, N., Branton, C., & Callis-Duehl, K. (2025). 3D Plants: The Impact Of Integrating Science, Design, And Technology On High School Student Learning And Interests In STEAM Subjects And Careers. *Disciplinary and Interdisciplinary Science Education Research*, *7*(1), 1. https://doi.org/10.1186/s43031-025-00120-4

Aris, N. M., Ibrahim, N. H., & Halim, N. D. A. (2024). Innovate to Educate: The Development and Validation of the Design Thinking Chemistry Module. *International Journal of Academic Research in Progressive Education and Development*, *13*(1). https://doi.org/10.6007/IJARPED/v13-i1/21103

Atit, K., Power, J. R., Veurink, N., Uttal, D. H., Sorby, S., Panther, G., Msall, C., Fiorella, L., & Carr, M. (2020). Examining The Role Of Spatial Skills And Mathematics Motivation On Middle School Mathematics Achievement. *International Journal of STEM Education*, *7*(1), 38. Retrieved from https://doi.org/10.1186/s40594-020-00234-3

Bone, E., Salamito, S. E., Black, B., Carew, P., Ona, A., Yau, G., Picking, B., & Pang, A. (2024). Scaling-Up Technology-Enhanced Authentic Learning Across A University-Wide Curriculum Innovation Program. *ASCILITE Publications*, 159–161. https://doi.org/10.14742/apubs.2024.1160

Burns, L. E. A., & Davenport, C. E. (2025). Characterizing The Growth In Spatial Thinking Skills In Undergraduate Meteorology Students Across The Curriculum. *Bulletin of the American Meteorological Society*, *106*(2), E275–E289. https://doi.org/10.1175/BAMS-D-23-0324.1

Costa, A. M., Escaja, N., Fité, C., González, M., Madurga, S., & Fuguet, E. (2023). Problem-Based Learning In Graduate And Undergraduate Chemistry Courses: Face-To-Face And Online Experiences. *Journal Of Chemical Education*, *100*(2), 597–606. https://doi.org/10.1021/acs.jchemed.2c00741

Dewi, A. E. R., Kalil, N. C., Hidayat, H., & Juniati, S. R. (2024). Exploring The Relationship Between Teacher Professional Development And Student Learning Outcomes. *Journal Of Pedagogi*, *1*(5), 109–116. https://doi.org/10.62872/a5xyk576

Dibyantini, R. E., Amdayani, S., Siregar, M. I., & Syafriani, D. (2023). Application of STEM-PjBL Based Chemistry Module to Improve Science Literacy and Student Learning Motivation. *Jurnal Penelitian Pendidikan IPA*, *9*(SpecialIssue), 95–102. https://doi.org/10.29303/jppipa.v9iSpecialIssue.5872

Hamidi, A., Akmala, R., Suyanta, & Wilujeng, I. (2024). Development of PBL Based E-Modules to Boost Students' Science Process Skills. *Jurnal Penelitian Pendidikan IPA*, *10*(2), 820–827. https://doi.org/10.29303/jppipa.v10i2.5939

Hanum, W. N., Nuha, U., & Ridlo, Z. R. (2024). Development Of Scaffolding-Based Science E-Modules To Improve Junior High School Students' Scientific Reasoning. *ORBITA: Jurnal Pendidikan Dan Ilmu Fisika*, *10*(2), 185. https://doi.org/10.31764/orbita.v10i2.26773

Himmah, R., Jatmiko, B., Prahani, B. K., & Rizki, I. A. (2024). Science Literacy Competency Profile of Science Education Students in Understanding the Concept of Thermodynamics. *IJORER : International Journal of Recent Educational Research*, *5*(6), 1600–1615. https://doi.org/10.46245/ijorer.v5i6.724

Ibrahim, M., & Mohd Badli, N. A. (2025). STEM in chemistry. *LUMAT: International Journal on Math, Science and Technology Education*, *12*(4), 4. https://doi.org/10.31129/LUMAT.12.4.2445

Jamaluddin, R., Shah, N. H. M., Puad, M. H. M., Kang, E. K. M. S., & Jusoh, R. (2023). The integration of Science Technology Engineering and Mathematics (STEM) in home science: teachers' understanding and challenges. *Journal of Advanced Research in Applied Sciences and Engineering Technology, 31*(2), 42-50. https://doi.org/10.37934/araset.31.2.4250

Jung, I. (2024). Week 7: Writing the Qualitative Methods Section. In *Pathways to International Publication in the Social Sciences* (pp. 135–145). Springer Nature Singapore. https://doi.org/10.1007/978-981-96-0801-0_13

Khan, S. N. (2024). Qualitative Research Method - Phenomenology. *Asian Social Science*, *10*(21). https://doi.org/10.5539/ass.v10n21p298

Krokhmal, A., Tymchenko, A., Shayner, H., Lytvynov, A., & Drobin, A. (2024). Use Of Interactive Electronic Educational Video Resources For Professional Training Of Specialists. *Eduweb*, *18*(3), 223–238. https://doi.org/10.46502/issn.1856-7576/2024.18.03.17

Letnar, B., Klostermann, A., & Schmidt, M. (2025). Supporting Complex Skill Learning With Digital Tools In Tertiary Education: Educator's Perspective. *Current Issues in Sport Science (CISS)*, *10*(2), 032. https://doi.org/10.36950/2025.2ciss032

Liu, J., Aziku, M., Qiang, F., & Zhang, B. (2024). Leveraging Professional Learning Communities In Linking Digital Professional Development And Instructional Integration: Evidence From 16,072 STEM Teachers. *International Journal of STEM Education*, *11*(1), 56. https://doi.org/10.1186/s40594-024-00513-3

Ma'fiyah, I., Riyani, R., & Rahma Yuliana, C. (2025). Investigating The Role Of Cbcl Listening E-Module

In Fostering 21st Century Skills: An Experimental Study. *Indonesian EFL Journal*, *11*(1), 13–20. https://doi.org/10.25134/ieflj.v11i1.11159

Nguyen, T. P. L., Nguyen, T. H., & Tran, T. K. (2020). STEM education in secondary schools: *Teachers' perspective towards sustainable development. Sustainability (Switzerland)*, *12*(21), 1–16. https://doi.org/10.3390/su12218865

Oanh, D. T. K. (2024). Integrated STEM Education Competence Framework for University Lecturers. *European Journal of Educational Research*, *14*(1), 135–150. https://doi.org/10.12973/eu-jer.14.1.135

Oktariani, O., & Saputri, E. R. (2024). Development of Science, Technology, Engineering, and Mathematics (STEM)-Based Chemistry E-module Learning Materials on the Topic of Reaction Rate. *JINoP (Jurnal Inovasi Pembelajaran)*, *10*(1), 115–129. https://doi.org/10.22219/jinop.v10i1.29013

Pathuddin, P., Ningsih, P., Afadil, A., Rahmawati, S., & Ahmar, D. S. (2024). Training On E-Module Compilation Based On Pjbl With A Stem Approach To Develop The Numeracy Literacy Ability Of Mathematics Teachers In Donggala District. *Abdi Dosen : Jurnal Pengabdian Pada Masyarakat*, *8*(3), 1172–1181. https://doi.org/10.32832/abdidos.v8i3.2461

Pepin, B., & Rezat, S. (2025). Symposium—Towards Innovative Practices in Mathematics Education: Teachers' and Students' Choice and Use of Digital Resources. *In Recent Advances in Mathematics Textbook Research and Development* (pp. 123–126). Springer Nature Singapore. https://doi.org/10.1007/978-981-97-8426-4_17

Pepin, B., & Kock, Z. J. (2021). Students' use of resources in a challenge-based learning context involving mathematics. *International Journal of Research in Undergraduate Mathematics Education, 7*(2), 306-327. https://doi.org/10.1007/s40753-021-00136-x

Rosman. N. L., Ismail, A., & Nasir. M. N. M., (2024). The Relationship Between Digital Competencies And 21st Century Skills Of Technology Students' Construction Of Vocational Colleges. *International Journal of Innovation and Industrial Revolution*, *6*(16), 55–64. https://doi.org/10.35631/IJIREV.616004

Saxena, R. R., Voss, W., & Mahmood, S. (2024). *Empowering Learners Globally: A User Interface and User Experience Design Case Study Describing the Development of a Mobile Application That Bridges the Educational Divide Through Accessible Instructional Resources*. Authorea Preprints. https://doi.org/10.36227/techrxiv.172175659.90097054/v1

Sekaringtyas, T., Suyono, S., & Hadi, W. (2024). The Influence of Understanding Science Concepts, Critical Thinking Skills, and Scientific Literacy on Scientific Attitudes Class IV Primary School Students. *Journal of Ecohumanism*, *3*(8). https://doi.org/10.62754/joe.v3i8.5228

Septiadevana, R., & Abdullah, N. (2024). Designing a STEM Project-Based Learning Module for Scientific Literacy and Critical Thinking Elementary School Students. *Jurnal Pendidikan Sains Indonesia*, *12*(3), 662–682. https://doi.org/10.24815/jpsi.v12i3.38255

Simmons, D., Clark, J. S., Goodson, L., Darvishinia, N., & Ebrahimi, M. (2023). Exploring teachers' perceived needs for quality STEM learning experiences. *Journal of Technology and Teacher Education, 31*(4), 459-492. Retrieved from https://www.learntechlib.org/primary/p/222406/

Siregar, L., & Silaban, S. (2023). Development and Implementation of Chemistry STEM-Based Module on Buffer Solution Material in Senior High School. *Jurnal Teknologi Pendidikan : Jurnal Penelitian Dan Pengembangan Pembelajaran*, *8*(4), 737. https://doi.org/10.33394/jtp.v8i4.8572

Slipchyshyn, L., Holiiad, I., Yakymovych, T., Dubovyk, O., & Tropina, M. (2024). Post-War Modernization Of Education: The Digital Learning Environment As A Key Element Of The Innovative Educational Cluster. *Psychological and Pedagogical Problems of Modern School*, *2(12)*, 56–67. https://doi.org/10.31499/2706-6258.2(12).2024.315010

Ulwan, R., Enawaty, E., Muharini, R., Hairida, H., & Lestari, I. (2024). Description of Science Literacy Epistemic Knowledge Ability of Chemistry Education Students on the Material of Colligative Properties of Solutions. *Hydrogen: Jurnal Kependidikan Kimia*, *12*(6), 1512. https://doi.org/10.33394/hjkk.v12i6.14230

Wang, W., Wang, H., Wang, Y., Liu, J., & Sun, K. (2025). Research On The Classification Of Dimensional Performance And Feature Extraction Of Primary School Students' Core Literacy In Science Curriculum. *International Scientific Technical and Economic Research*, 115–126. https://doi.org/10.71451/ISTAER2510

Wati, S., Syafryadin, S., & Apriani, E. (2021). Learning Module Development On Compiling Exposition And Argumentation Text Using Project-Based Learning. *English Review: Journal of English Education,* 9(2), 355-366. https://doi.org/10.25134/erjee.v9i2.4370

Widiana, L. V. W., Prayitno, B. A., & Sugiharto, B. (2024). Framework Problem Solving Based Augmented Reality Media To Empower Scientific Explanation Skill. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, *10*(2), 631–639. https://doi.org/10.22219/jpbi.v10i2.32387

Zhan, Z., Shen, W., Xu, Z., Niu, S., & You, G. (2022). A bibliometric analysis of the global landscape on STEM education (2004-2021): towards global distribution, subject integration, and research trends. *Asia Pacific Journal of Innovation and Entrepreneurship, 16*(2), 171-203. https://doi.org/10.1108/APJIE-08-2022-0090