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ICT-Based Teaching Materials on Science Learning to Improve 21st-Century Skills : A Systematic Review

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ABSTRACT

Objective: This research aims to evaluate how integrating ICT teaching materials in science learning enhances students' active involvement and develops critical 21st-century skills necessary for their daily lives and future careers. **Method:** A Systematic Literature Review (SLR) method is used in this study to review recent research on ICT teaching materials to improve skills for the 21st century. The results obtained were 23 articles. **Results:** The analysis shows that 1) E-modules are the most widely used teaching material, 2) Improving 21st-century skills, namely critical thinking. Thus, e-modules are an ideal solution to support the development of critical thinking skills in the modern era. **Novelty:** The novelty of this study lies in its emphasis on e-modules as a particularly effective tool for nurturing critical thinking skills among students. This focus represents a significant advancement in the educational field by demonstrating how e-modules can serve as a targeted and strategic approach to cultivating essential 21st-century skills. Using modern technology in learning, e-modules make learning more exciting and help students think critically. This is important for succeeding in today's world, which is becoming more complex and relies on technology.

INTRODUCTION

Science education necessitates a student-centered approach, engaging students actively in learning. Therefore, students must be involved and participate actively in educational activities. Science instruction should include hands-on experiences to enhance understanding rather than relying solely on rote memorization. As a subject, science is integral to various educational levels due to its significant role in achieving established educational objectives. Thus, mastery and understanding of science is important for every student (Supena, 2021). Effective science learning can aid students in cultivating critical thinking, analytical abilities, and problem-solving skills (Fitriani et al., 2020; Saphira et al., 2022b, 2022a; Xu et al., 2023; Zulyusri et al., 2023). Consequently, science stands as a vital discipline for preparing students to face future challenges (Belbase et al., 2022; Darling-Hammond et al., 2020; Dishon & Gilead, 2021; Manz et al., 2020; Matthews, 2024). Therefore, incorporating practical experience in science education is crucial for equipping students with the essential skills for their daily lives and future careers.

Advancements in information and communication technology (ICT) enable the adaptation of teaching and learning methods to meet the preferences and needs of students. ICT encompasses technologies used to manage, process, and transmit information without restrictions on location or time, making data flow highly accessible (Ateş & Garzón, 2022). In addition, Akcil (2021) stated that ICT significantly influences education by enhancing students' interest, creativity, and motivation to learn. Consequently, integrating ICT into education facilitates learning and is crucial in motivating students to pursue continuous learning.

ICT-based learning typically involves using mobile devices such as computers, laptops, mobile phones, audio players, and e-books. This represents an example of ICT applications in education (Ali, 2020; Ashraf et al., 2022; Mohammed & Kinyo, 2020; Suzianti & Paramadini, 2021; Thongmak, 2021). For effective learning, it is essential to support the availability of teaching materials, including animated videos, PowerPoints, images, e-books, e-student worksheets, and e-modules. Incorporating ICT teaching resources into the classroom effectively is a difficult process that calls for a strong technological foundation, improved teacher preparation, and the willingness and drive of educators. (Kazmi & Mohammad, 2023). Educators have predominantly relied on traditional teaching methods for centuries, resulting in a conventional learning process (Xhelili, 2021). Despite the challenges associated with its implementation, using ICT in education holds significant potential to enhance learning effectiveness when applied correctly.

Technology can help connect learning with real-life situations. Learning technology is appealing because it allows various classes to connect across the boundaries of space, time, and geography. Using Hark (2023), a socio-constructivist perspective, mobile device communication capabilities can promote teamwork and establish the foundation for mobile learning. In this 21st century now, students need to master the skills known as the 4C: Critical Thinking, Communication, Collaboration, and Creativity (Haryani et al., 2021; Limna et al., 2022; Pardede, 2020; Sari & Wardhani, 2020; Somphol et al., 2022; Wahyuddin et al., 2022). Developing critical and creative thinking and other thinking skills is important for students (Negoro, 2023). These skills are referred to as 21st-century skills. Technological advancements have brought 21st-century skills into everyday life. This strategy includes integrating technology learning into the classroom to achieve learning goals through technology (Özer & Kuloğlu, 2023). Technology can be a solution in education (Ibrahimi, 2024). In addition, these skills should be incorporated into current learning strategies.

In the study of Dunstan (2024), it is explained that ICT serves not only as a tool for teaching language but also as a medium for providing interactive and culturally relevant digital teaching materials at the elementary school level. Additionally, the study offers empirical data from surveys that reveal teachers' perspectives on implementing ICT in instructional practices. This highlights the dual role of ICT in enhancing language instruction and cultural education while offering valuable insights into educators' views and experiences with integrating technology into their teaching methods (Domu & Mangelep, 2024; Sutiyono et al., 2023).

Based on the review above, this study aims to systematically review the results of the latest research on ICT teaching materials to improve 21st-century skills from 2018 to 2024. This review comes from an empirical article on systematic content analysis science education. Given the increasing prevalence of ICT in education, this study aims to investigate the potential of ICT-based teaching materials to foster the development of 21st-century skills. Some research questions created to guide the research are presented as follows: 1) What types of ICT teaching materials are most commonly used in science learning? 2) What 21st-century skills are essential for effectively using ICT in science learning?

RESEARCH METHOD

This study conducted a thorough literature review. Researchers use Systematic Literature Review (SLR) to identify, review, evaluate, and interpret any available research. This method allows researchers to conduct systematic reviews and identification of journals by following the procedures set at each stage.

The SLR method encourages evidence-based activities, allows for more objective research assessments, and discovers new research topics. According to PRISMA guidelines, the study uses electronic scientific databases, including Eric, Scopus, and Sinta, to identify relevant studies. The choice of database is based on its multidisciplinary scope, accessibility, and relevance to the subject. Frameworks are used to conduct literature searches in electronic scientific databases.

The procedure is divided into four stages:

1. Identification;
2. Screening;
3. Eligibility;
4. Included (Ridho, 2023).

In **Figure 1**, the first stage involves systematically searching the electronic database. Studies were selected if they met the following inclusion criteria:

1. This study is empirical research on learning that uses ICT in the teaching and learning process to improve 21st-century skills.
2. This study was published between 2018 and 2024. Figure 1 presents a graph chart of PRISMA criteria**.**

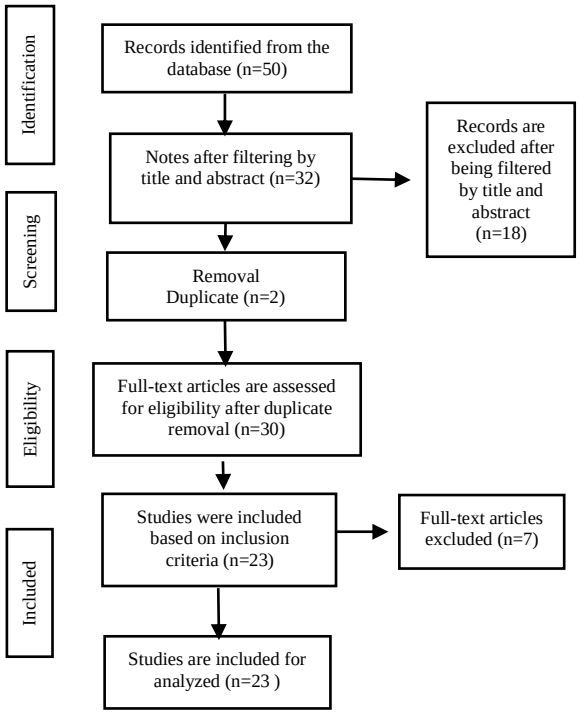

Figure 1. Prisma criteria.

This search process resulted in 50 articles. Furthermore, the research's title and abstract were selected in the second stage. In total, this screening process resulted in 32 relevant articles. When examining the results, two of them were found to be duplicates. The assessment of the feasibility of thirty selected full-text articles was carried out in the third stage. This process involves carefully reading all papers and selecting those

eligible for inclusion. After this process, 23 scientific articles that met the selection criteria were considered for final extraction. In the final stage, the quality of the scientific article (n = 23) is assessed using research questions.

RESULTS AND DISCUSSION

Results

ICT teaching materials are most commonly used in science learning

An article search in various national and international journals and the researcher found 23 articles. These articles are related to ICT teaching materials in science learning to improve 21st-century skills presented in **Table 1**.

Table 1. Results of ICT teaching materials analysis.

ICT Teaching Materials	F	P
E-Module	8	34.78%
Interactive Multimedia	3	13.04%
PowerPoint	1	4.35%
Worksheet	1	4.35%
E-learning	3	13.04%
E-book	1	4.35%
PhET	1	4.35%
E-student worksheet	1	4.35%
Augmented Reality	4	17.39%

21st-century skills are essential for the effective use of ICT in science learning

Moreover, the Partnership for 21st Century Skills outlines the essential competencies for students, encompassing abilities for innovation and learning (Nesri & Kristanto, 2020). These competencies include critical thinking, collaboration, creativity, and communication, often referred to as the 4C skills (Trisnawati, 2019)—Table 2 shows the results of the analysis of skill improvement in the 21st century.

Table 2. Analysis of 21st century skill improvement.

21st Century Skills	F	P
Critical Thinking	16	69.57%
Creativity	3	13.04%
Collaboration	3	13.04%
Communication	1	4.35%

The analysis of the year range of the most analyzed articles is presented **in Figure 2.**

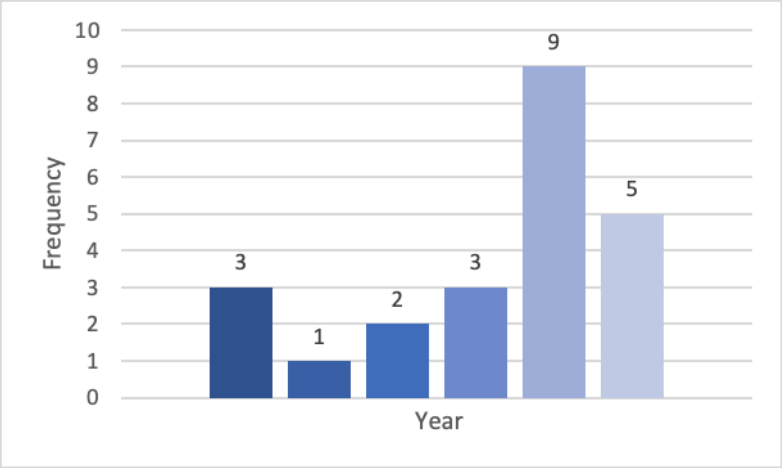

Figure 2. Article year range.

Table 3 presents an analysis of educational levels that use ICT teaching materials to improve 21st-century skills. Table 4 shows all 32 articles included in the inclusion criteria**.**

Table 3. Level of education.

Level of Education	F	P
Elementary School	5	21.74%
Junior High School	7	30.44%
Senior High School	8	34.78%
University	3	13.04%

Table 4. Inclusion criteria article.

Heading	Article Name	Reference
"Development of an E-Module Based on Problem-Based Learning to Grow Critical Thinking Skills of Class V Elementary School Students"	International Journal of Education and Research	(Putra & Haryani, 2023)
"Developing Inquiry-Based Lectora Multimedia in Order to Increase the Logical Ability and The Creative Thinking"	Journal of Prima Edukasia	(Noviani & Wangid, 2018)
"The effectiveness of physics e-modules based on creative problem-solving learning model integrated with 21st-Century Skills"	Indonesian Journal of Science and Mathematics Education	(Andriani, 2023)
"Development of E-Modules Based on Mobile Learning Applications to Improve Students' Critical Thinking Skills in Science Subject"	JPPS (Journal of Science Education Research)	(Uma'iyah, 2023)
"Implementing a Project-Based Collaborative Learning Approach Using PowerPoint to Improve Students' 21st-Century Skills"	E-Learning and Digital Media	(Aifan, 2022)
"Development of online student worksheet based on a scientific approach to improving critical thinking ability in junior high school."	J. Incandescent Natural Sciences	(Wulan, 2023)
"Dynamic Blend of Ethnoscience and Inquiry in a Digital Learning Platform (E-Learning) For Empowering Future Science Educators' Critical Thinking"	Journal of Education And E-Learning Research	(Kuanganovna, 2023)

Heading	Article Name	Reference
"E-Book With Problem-Based Learning to Improve Student Critical Thinking in Science Learning at Elementary School"	International Journal of Interactive Mobile Technologies (IJIM)	(Susanto, 2022)
"The Practicality and Effectiveness of Collaborative Creativity Learning (CCL) Model by Using Phet Simulation to Increase Students' Scientific Creativity"	International Journal of Instruction	(Astutik & Prahani, 2018)
"The Effect of The Science Web Module Integrated on Batik's Local Potential Towards Students' Critical Thinking and Problem Solving (Thinking Skill)"	Journal of Science Learning	(Putri & Aznam, 2019)
"Student's Critical Thinking Skills Through Discovery Learning Model Using E-Learning on Environmental Change Subject Matter"	European Journal of Educational Research	(Chusni, 2020)
"Development of Android-Based Interactive Multimedia to Enhance Critical Thinking Skills in Learning Matters"	Journal Of Science Learning	(Hamdani, 2022)
"Development of Interactive E-LKPD Based on Creative Thinking Skills on The Concept of Environmental Change"	JPBI (Indonesian Journal of Biology Education)	(Ricky & Zulfiani, 2023)
"Enhancing Students' Critical Thinking and Visualisation Skills Through Mobile Augmented Reality"	Knowledge Management & E-Learning	(Saidin, 2024)
"Adaptive E-Learning Module in Teaching Physical Science for Improved Student Engagement and Critical Thinking Skills"	IJSART (International Journal for Science and Advance Research In Technology)	(Handog & Aliazas, 2024)
"Improving Critical Thinking Skills Students Through Problem-Based Learning E-Module"	Science Education Research Journal	(Sulhan, 2023)
"Development of Interactive Multimedia Learning Materials for Improving Critical Thinking Skills"	International Journal of Information and Communication Technology Education	(Djamas, 2018)
"Investigating The Role of Augmented Reality in Supporting Collaborative Learning in Science Education: A Case Study"	International Journal of Engineering Pedagogy	(Kuanbayeva, 2024)
"Developing Students' Critical Thinking Skills and Argumentation Abilities Through Augmented Reality–Based Argumentation Activities in Science Classes"	Science & Education	(Demircioglu, 2023)
"Science Learning Game (SLG) Based on Augmented Reality Enhances Science Literacy and Critical Thinking Students Skills"	Science Education Research Journal	(Fatih, 2024)
"The effectiveness of developing science e-modules based project-based learning to improve the communication skills of grade 5th students"	Pendas Horizon Journal	(Asriani, 2023)
"Profile of Students' Critical Thinking Ability: Implementation of E-Modul Based on Problem-Based Learning"	IJORER: International Journal of Recent Educational Research	(Mahmudah, 2022)

Heading	Article Name	Reference
"Effectiveness of E-Module to Improve Students' Critical Thinking Skills in High School Science Learning: Literature Study"	International Journal of Science Education and Science	(Diniyatushoaliha, 2024)

Discussion

ICT teaching materials are most commonly used in science learning

The findings from the analysis of ICT teaching materials utilization in science education revealed that the highest percentage, 34.78%, was attributed to the implementation of E-modules. These E-modules encompassed various approaches, such as Problem-Based Learning, Physics-focused modules, mobile learning-based modules, those rooted in local wisdom, and Project-Based Learning modules.

Learning media, such as learning modules, are developing rapidly in education. According to Khikmiyah (2021), an e-module is a digital tool utilized within the educational journey, designed with structured methods, resources, and evaluations to systematically guide students toward achieving competency objectives at various levels of complexity—these electronically formatted modules aid in learning and fostering informed perspectives (Laili, 2019). E-modules are self-paced learning tools that combine learning materials (Anoda, 2022; Fathiya & Asrizal, 2022; Hakim et al., 2021; Manalastas & De Leon, 2021; Sulaiman, 2023). As Siregar and Harahap (2020) outlined, E-modules are electronic modules designed to be presented digitally, aiming to enhance students' engagement and enthusiasm for learning. Another perspective suggests that e-modules are electronically crafted mediums with structured limitations, methodologies, and assessment tools systematically tailored to varying levels of complexity to foster the acquisition of desired 21st-century competencies.

21st-century skills are essential for the effective use of ICT in science learning

The broad range of competencies students require are often considered 21st-century talents. 21st-century learning often refers to the broader concept of education (Andrian & Rusman, 2019). As a result, teachers in the twenty-first century need to be able to incorporate ICT into the classroom. The analysis of skill improvement in the twenty-first century shows that critical thinking reaches the highest level of 69.57%, and communication reaches the lowest level of 4.35%. When people engage in critical thinking, they constantly have a more profound curiosity about the material. Critical thinking skills are crucial to preparing students for future challenges (Maulidah, 2021).

The analysis of the most frequently used articles revealed that 9 out of 23 were published in 2023. Focusing on the educational levels, 8 of the 23 articles highlighted using ICT teaching materials to enhance 21st-century skills in senior high school students. This suggests a particular need for teaching materials that support and improve students' critical thinking abilities at this level. Therefore, senior high schools should leverage technology to the fullest extent in their teaching materials (Aditya, 2021; Hennessy et al., 2022; Major et al., 2021; Olszewski & Crompton, 2020; Sanusi et al., 2022). By integrating modern technology into the learning process, e-modules offer a more engaging and interactive approach to education (Mitra & Wahyudin, 2024). This enhances student interest and motivation and fosters the development of critical thinking skills, which are essential for navigating the increasingly complex and technology-dependent world we live in today.

CONCLUSION

Fundamental Finding: This research contributes fundamentally to the field by highlighting the role of ICT teaching materials in enhancing 21st-century skills, particularly critical thinking, in science education. The findings underscore the prevalence of e-modules as practical tools for interactive and personalized learning experiences at the high school level. By leveraging digital technologies, e-modules facilitate active student engagement, fostering more effective teaching and learning environments. **Implication:** Integrating ICT teaching materials, such as e-modules, into science education offers substantial benefits. These tools enhance critical thinking and 21st-century skills, provide interactive and personalized learning experiences, and increase student engagement. Additionally, they modernize teaching practices and support educators by improving the quality of instruction. **Limitation:** However, it is important to acknowledge the limitations of this study, mainly the focus on high school settings and the predominance of recent literature from 2023. Implications for future research include expanding the scope to different educational levels and subject areas and exploring diverse methodologies to assess the impact of ICT teaching materials comprehensively. **Future Research:** This study lays a solid foundation for future researchers aiming to innovate and optimize educational practices through integrating digital technologies, ultimately advancing the cultivation of critical thinking skills essential for success in the modern era.

REFERENCES

Aditya, D. S. (2021). Embarking digital learning due to COVID-19: Are teachers readY? *Journal of Technology and Science Education*, *11*(1), 104–116. https://doi.org/10.3926/jotse.1109

Aifan, H. (2022). Implementing a project-based collaborative learning approach using PowerPoint to improve students' 21st- century skills. *E-Learning and Digital Media*, *19*(3), 258–273. https://doi.org/10.1177/20427530211030642

Akcil, U., Uzunboylu, H., & Kinik, E. (2021). Integration of technology to learning-teaching processes and google workspace tools: A literature review. *Sustainability (Switzerland)*, *13*,(9), 1-10. https://doi.org/10.3390/su13095018

Ali, W. (2020). Online and remote learning in higher education institutes: a necessity in light of COVID-19 pandemic. *Higher Education Studies*, *10*(3), 16-25. https://doi.org/10.5539/hes.v10n3p16

Andrian, Y., & Rusman, R. (2019). Implementation of 21st century learning in the 2013 curriculum. *Journal of Educational Research* Sciences, *12*(1), 14-23.

Andriani, R., Taufiq H.A., & Elisyah, N. (2023). The effectiveness of physics e-modules based on creative problem-solving learning model integrated with 21st-century skills. *Indonesian Journal of Science and Mathematics Education*, *6*(1), 48–58. https://doi.org/10.24042/ijsme.v5i1.14584

Anoda, M. S. (2022). Experiences of teachers, parents and students in learning delivery modalities : A qualitative inquiry. *International Journal of Advanced Research and Publications*, *5*(3), 28–41.

Ashraf, M. A., Iqbal, J., Arif, M. I., & Asghar, M. Z. (2022). Fostering ICT competencies in blended learning: Role of curriculum content, material, and teaching strategies. *Frontiers in Psychology*, *13*, 1–13. https://doi.org/10.3389/fpsyg.2022.758016

Asriani, A., Retno, T., & Hambari. (2023). The effectiveness of developing science e-modules based project-based learning to improve the communication skills of grade 5th students. *Journal of Pendas* Horizons, *9*(4), 750–761. https://doi.org/10.31949/jcp.v9i4.6502

Astutik, S., & Prahani, B. K. (2018). The practicality and effectiveness of collaborative creativity learning (CCL) model by using PhET simulation to increase students' scientific creativity.

International Journal of Instruction, *11*(4), 409–424. http://dx.doi.org/10.12973/iji.2018.11426a

Ateş, H., & Garzón, J. (2022). Drivers of teachers' intentions to use mobile applications to teach science. *Education and Information Technologies*, *27*(2), 2521–2542. https://doi.org/10.1007/s10639-021-10671-4

Belbase, S., Mainali, B. R., Kasemsukpipat, W., Tairab, H., Gochoo, M., & Jarrah, A. (2022). At the dawn of science, technology, engineering, arts, and mathematics (STEAM) education: prospects, priorities, processes, and problems. *International Journal of Mathematical Education in Science and Technology*, *53*(11), 2919–2955. https://doi.org/10.1080/0020739X.2021.1922943

Chusni, M. M., Saputro, S., Rahardjo, S. B., & Suranto, S. (2020). Student's critical thinking skills through discovery learning model using e-learning on environmental change subject matter. *European Journal of Educational Research*, *10*(3), 1123–1135. https://doi.org/10.12973/EU-JER.10.3.1123

Darling-Hammond, L., Flook, L., Cook-Harvey, C., Barron, B., & Osher, D. (2020). Implications for educational practice of the science of learning and development. *Applied Developmental Science*, *24*(2), 97–140. https://doi.org/10.1080/10888691.2018.1537791

Demircioglu, T., Karakus, M., & Ucar, S. (2023). Developing students' critical thinking skills and argumentation abilities through augmented reality–based argumentation activities in science classes. *Science and Education*, *32*(4), 1165–1195. https://doi.org/10.1007/s11191-022-00369-5

Diniyatushoaliha, A. (2024). Effectiveness of e-module to improve students' critical thinking skills in high school science learning: Literature study. *International Journal of Science Education and Science*, *1*(1), 6–12. https://doi.org/10.56566/ijses.v1i1.106

Dishon, G., & Gilead, T. (2021). Adaptability and its discontents: 21st-century skills and the preparation for an unpredictable future. *British Journal of Educational Studies*, *69*(4), 393–413. https://doi.org/10.1080/00071005.2020.1829545

Djamas, D., Tinedi, V., & Yohandri, Y. (2018). Development of interactive multimedia learning materials for improving critical thinking skills. *International Journal of Information and Communication Technology Education*, *14*(4), 66–84. https://doi.org/10.4018/IJICTE.2018100105

Domu, I., & Mangelep, N. O. (2024). Optimizing elementary teachers' ability in designing realistic and ICT-based mathematics learning. *Communnity Development Journal, 5*(2), 3900–3906. https://doi.org/10.31004/cdj.v5i2.27632

Dunstan, T. F., & Ismail, H. H. (2024). Using ICT-based interventions to boost malaysian young rural learners' interest and motivation in reading english materials: A literature review. *International Journal of Academic Research in Progressive Education and Development*, *13*(1), 1-11.

Fathiya, N., & Asrizal, A. (2022). Development of STEM education integrated sound and light waves e-module for critical and creative thinking skills of high school students. *Pillar of Physics Education*, *15*(4), 276-285. https://doi.org/10.24036/13528171074

Fatih, M., Alfi, C., & Muqtafa, M. A. (2024). Science learning game (SLG) based on augmented reality enhances science literacy and critical thinking students skills. *Journal of Science Education Research*, *10*(2), 973–981. https://doi.org/10.29303/jppipa.v10i2.6107

Fitriani, A., Zubaidah, S., Susilo, H., & Al Muhdhar, M. H. I. (2020). PBLPOE: A learning model to enhance students' critical thinking skills and scientific attitudes. *International Journal of Instruction*, *13*(2), 89–106. https://doi.org/10.29333/iji.2020.1327a

Hakim, N., Hakim, A., & Wahid, M. S. (2021). Interactive e-module development in multimedia learning. *AL-ISHLAH: Jurnal Pendidikan*, *13*(3), 2293–2300. https://doi.org/10.35445/alishlah.v13i3.863

Hamdani, S. A., Prima, E. C., Agustin, R. R., Feranie, S., & Sugiana, A. (2022). Development of android-based interactive multimedia to enhance critical thinking skills in learning matters. *Journal of Science Learning*, *5*(1), 103–114. https://doi.org/10.17509/jsl.v5i1.33998

Handog, S., & Aliazas, J. V. (2024). Adaptive e-learning module in teaching physical science for improved student engagement and critical thinking skills. *IJSART*, *10*(3), 1-12. https://doi.org/10.5281/zenodo.10947524

Hark, S. N. (2023). Teacher and Student in the 21st Century: A Mixed Design Research. *International Journal of Psychology and Educational Studies*, *10*(3), 758–772. https://doi.org/10.52380/ijpes.2023.10.3.1128

Haryani, E., Cobern, W. W., Pleasants, B. A. S., & Fetters, M. K. (2021). Analysis of teachers' resources for integrating the skills of creativity and innovation, critical thinking and problem solving, collaboration, and communication in science classroom. *Jurnal Pendidikan IPA Indonesia*, *10*(1), 92–102. https://doi.org/10.15294/jpii.v10i1.27084

Hennessy, S., D'Angelo, S., McIntyre, N., Koomar, S., Kreimeia, A., Cao, L., Brugha, M., & Zubairi, A. (2022). Technology use for teacher professional development in low- and middle-income countries: A systematic review. *Computers and Education Open*, *3*, 1-12. https://doi.org/10.1016/j.caeo.2022.100080

Ibrahimi, E., Miri, F., & Koçiaj, I. (2024). An assessment of the integration of ICTs into teaching processes by science teachers: The case of albania. *Journal of Technology and Science Education*, *14*(2), 405–417. https://doi.org/10.3926/jotse.2319

Kazmi, Z., & Mohammad, A. (2023). Use of information and communication technologies in teaching of science: A perception and practices of science teachers. *TOJET: The Turkish Online Journal of Educational Technology*, 22(1), 1-11. https://orcid.org/0000-0002-6452-1150

Khikmiyah, F. (2021). Implementation of web live worksheet based on problem-based learning in mathematics learning. *Journal of Pedagogy, 6*(1), 1-12. https://doi.org/10.30605/pedagogy.v6i1.1193

Kuanbayeva, B., Shazhdekeyeva, N., Zhusupkaliyeva, G., Mukhtarkyzy, K., & Abildinova, G. (2024). Investigating the role of augmented reality in supporting collaborative learning in science education: A case study. *International Journal of Engineering Pedagogy*, *14*(1), 149–161. https://doi.org/10.3991/ijep.v14i1.42391

Kuanganovna, B. A., Reschke, H. K., Alena, G., Zulkiya, M., & Ismailbekovna, S. L. (2023). Dynamic blend of ethnoscience and inquiry in a digital learning platform (e-learning) for empowering future science educators' critical thinking. *Journal of Education and E-Learning Research*, *10*(4), 829–836. https://doi.org/10.20448/jeelr.v10i4.5233

Laili, I. (2019). The effectiveness of the development of project-based learning e-modules in installation subjects. *Journal of Imiah Education and Learning, 3*(3), 306–315. https://doi.org/10.23887/jipp.v3i3.21840

Limna, P., Siripipatthanakul, S., Phayaprom, B., & Siripipattanakul, S. (2022). The relationship between twenty-first-century learning model (4Cs), student satisfaction and student performance-effectiveness. *International Journal of Behavioral Analytics*, *2*(1), 1–18.

Mahmudah, S., Kirana, T., & Rahayu, Y. S. (2022). Profile of students' critical thinking ability: implementation of e-module based on problem-based learning. *IJORER : International Journal of Recent Educational Research*, *3*(4), 478–488. https://doi.org/10.46245/ijorer.v3i4.231

Major, L., Francis, G. A., & Tsapali, M. (2021). The effectiveness of technology-supported personalised learning in low- and middle-income countries: A meta-analysis. *British Journal of Educational Technology*, *52*(5), 1935–1964. https://doi.org/https://doi.org/10.1111/bjet.13116

Manalastas, R. S., & De Leon, S. P. (2021). Development and evaluation of electronic instructional module in matter. *European Journal of Humanities and Educational Advancements (EJHEA)*, *2*(8), 1–21. https://doi.org/10.13140/RG.2.2.36147.23848

Manz, E., Lehrer, R., & Schauble, L. (2020). Rethinking the classroom science investigation.

Journal of Research in Science Teaching, *57*(7), 1148–1174. https://doi.org/https://doi.org/10.1002/tea.21625

Matthews, M. R. (2024). Thomas kuhn and science education. *Science & Education*, *33*(3), 609–678. https://doi.org/10.1007/s11191-022-00408-1

Maulidah, E. (2021). 4Cs skills in learning for early childhood. *Childhood Education: Journal of Early Childhood Education*, *2*(1), 52-68. https://doi.org/10.2991/978-2-38476-086-2_44

Mitra, S. N., & Wahyudin, D. (2024). Implementation of liveworksheet-based interactive e-modules in learning islamic education to increase student motivation. *FITRAH: Jurnal Kajian Ilmu-Ilmu Keislaman, 10*(1), 1-16. https://doi.org/10.24952/fitrah.v10i1.10933

Mohammed, S., & Kinyo, L. (2020). Constructivist theory as a foundation for the utilization of digital technology in the lifelong learning process. *Turkish Online Journal of Distance Education*, *21*(4), 90–109. http://dx.doi.org/10.17718/tojde.803364

Negoro, R. A., Rusilowati, A., & Aji, M. P. (2023). Scratch-assisted waves teaching materials: ICT literacy and students' critical thinking skills. *Journal of Turkish Science Education*, *20*(1), 189–210. https://doi.org/10.36681/tused.2023.011

Nesri, F. D. P., & Kristanto, Y. D. (2020). Development of technology-assisted teaching modules to develop students' 21st century skills. *AXIOMS: Journal of Mathematics Education Study Program*, *9*(3), 480-492.

Noviani, S., & Wangid, M. N. (2018). Developing inquiry-based lectora multimedia in order to increase the logical ability and the creative thinking. *Journal of Prima Edukasia*, *6*(1), 89–101. https://doi.org/10.21831/jpe.v6i1.9653

Olszewski, B., & Crompton, H. (2020). Educational technology conditions to support the development of digital age skills. *Computers & Education*, *150*, 1-10. https://doi.org/10.1016/j.compedu.2020.103849

Özer, M., & Kuloğlu, A. (2023). The relationship between primary school teachers' perceptions of 21st century skills and digital literacy level. *Malaysian Online Journal of Educational Technology*, *11*(3), 173–183. https://doi.org/10.52380/mojet.2023.11.3.429

Pardede, P. (2020). Integrating the 4Cs into EFL integrated skills learning. *JET (Journal of English Teaching)*, *6*(1), 71–85. https://doi.org/10.33541/jet.v6i1.190

Putra, A. W., & Haryani, S. (2023). Development of an e-modul based on problem-based learning to grow critical thinking skills of class V elementary school students. *International Journal of Education and Research*, 11(5), 1-10.

Putri, A. S., & Aznam, N. (2019). The effect of the science web module integrated on batik's local potential towards students' critical thinking and problem solving (thinking skill). *Journal of Science Learning*, *2*(3), 92–96. https://doi.org/10.17509/jsl.v2i3.16843

Ricky, A., & Zulfiani, Z. (2023). Development of interactive e-LKPD based on creative thinking skills on the concept of environmental change. *JPBI (Indonesian Journal of Biology Education), 9*(2), 179–197. https://doi.org/10.22219/jpbi.v9i2.22389

Ridho, M. H., & Dasari, D. (2023). Systematic literature review: Identitas matematika dalam pembelajaran matematika. *Jurnal Cendekia: Jurnal Pendidikan Matematika*, *7*(1), 631-644. https://doi.org/10.31004/cendekia.v7i1.1989

Saidin, N. F., Yahaya, N., & Zulkifli, N. N. (2024). Enhancing students' critical thinking and visualisation skills through mobile augmented reality. *Knowledge Management & E-Learning: An International Journal*, 1–41. https://doi.org/10.34105/j.kmel.2024.16.001

Sanusi, I. T., Oyelere, S. S., & Omidiora, J. O. (2022). Exploring teachers' preconceptions of teaching machine learning in high school: A preliminary insight from Africa. *Computers and Education Open*, *3*, 1-11. https://doi.org/10.1016/j.caeo.2021.100072

Saphira, H. V., Rizki, I. A., Alfarizy, Y., Saputri, A. D., Ramadani, R., & Suprapto, N. (2022a). Profile of students' critical thinking skills in physics learning: a preliminary study of games application integrated augmented reality. *Journal of Physics: Conference Series*, 1-7. https://doi.org/10.1088/1742-6596/2377/1/012088

Saphira, H. V., Rizki, I. A., Alfarizy, Y., Saputri, A. D., Ramadani, R., & Suprapto, N. (2022b).

Profile of students ' critical thinking skills in physics learning : A preliminary study of games application integrated augmented reality *Journal of Physics: Conference Series*, *2377*, 1-9. https://doi.org/10.1088/1742-6596/2377/1/012088

Sari, D. M. M., & Wardhani, A. K. (2020). Critical thinking as learning and innovation skill in the 21st century. *Journal of English Language and Pedagogy*, *3*(2), 27–34. https://doi.org/10.36597/jelp.v3i2.8778

Siregar, A. D., & Harahap, L. K. (2020). Development of project-based learning based e-module integrated with hyperchem computing media on molecular form materials. *JPPS (Journal of Science Education Research), 10*(1), 331-338.

Somphol, R., Pimsak, A., Payoungkiattikun, W., & Hemtasin, C. (2022). Enhancing 4Cs skills of secondary school students using project-based learning. *Journal of Educational Issues*, *8*(2), 721-730. https://doi.org/10.5296/jei.v8i2.20367

Sulaiman, M. (2023). E-module based on blended learning for islamic religious education learning. *Indonesian Research Journal in Education |IRJE|*, *7*(1), 104–120. https://doi.org/10.22437/irje.v7i1.23885

Sulhan, A. S., Wilujeng, I., & Prasetyo, Z. K. (2023). Improving critical thinking skills students through problem based learning e-module. *Journal of Science Education Research*, *9*(11), 9481–9486. https://doi.org/10.29303/jppipa.v9i11.5231

Supena, I., Darmuki, A., & Hariyadi, A. (2021). The influence of 4C (constructive, critical, creativity, collaborative) learning model on students' learning outcomes. *International Journal of Instruction*, *14*(3), 873–892. https://doi.org/10.29333/iji.2021.14351a

Susanto, T. T. D., Dwiyanti, P. B., Marini, A., Sagita, J., Safitri, D., & Soraya, E. (2022). E-Book with problem based learning to improve student critical thinking in science learning at elementary school. *International Journal of Interactive Mobile Technologies*, *16*(20), 4–17. https://doi.org/10.3991/ijim.v16i20.32951

Sutiyono, A., Maximilian, A., & Ajeng, G. D. (2023). EFL teachers' perceptions regarding cultural awareness in ict-based learning in indonesian elementary school context. *IJLHE: International Journal of Language, Humanities, and Education, 6*(1), 40–52. https://doi.org/10.52217/ijlhe.v6i1.1212

Suzianti, A., & Paramadini, S. A. (2021). Continuance intention of e-learning: The condition and its connection with open innovation. *Journal of Open Innovation: Technology, Market, and Complexity*, *7*(1), 97-110. https://doi.org/10.3390/joitmc7010097

Thongmak, M. (2021). A model for enhancing employees' lifelong learning intention online. *Learning and Motivation*, *75*, 1-11. https://doi.org/10.1016/j.lmot.2021.101733

Trisnawati, W. W., & Sari, A. K. (2019). Integration of 21st century skills in the sociolinguistics module: 4c skills (collaboration, communication, critical thinking, and creativity). *Journal of Muara Pendidikan* 4(2), 455-466. https://doi.org/10.52060/mp.v4i2.179

Uma'iyah, N., Wahyuni, S., & Nuha, U. (2023). Development of e-modules based on mobile learning applications to improve students' critical thinking skills in science subject. *JPPS (Journal of Science Education Research), 12*(2), 122–137. https://doi.org/10.26740/jpps.v12n2.p122-137

Wahyuddin, W., Ernawati, E., Satriani, S., & Nursakiah, N. (2022). The application of collaborative learning model to improve student's 4cs skills. *Anatolian Journal of Education*, *7*(1), 93–102. https://doi.org/10.29333/aje.2022.718a

Wulan, E., Berlian, L., & Kurniasih, S. (2023). Development of online student worksheet based on scientific approach to improve critical thinking ability in Junior High School. *Journal of Incandescent and Mipa*, *18*(1), 50–56. https://doi.org/10.29303/jpm.v18i1.4336

Xhelili, P., Ibrahimi, E., Rruci, E., & Sheme, K. (2021). Adaptation and perception of online learning during COVID-19 pandemic by albanian university students. *International Journal on Studies in Education (IJonSE) International Journal on Studies in Education*, *3*(2), 103–111. https://doi.org/10.46328/ijonse.49

Xu, E., Wang, W., & Wang, Q. (2023). The effectiveness of collaborative problem solving in

promoting students' critical thinking: A meta-analysis based on empirical literature. *Humanities and Social Sciences Communications*, *10*(1), 1–11. https://doi.org/10.1057/s41599-023-01508-1

Zulyusri, Z., Elfira, I., Lufri, L., & Santosa, T. A. (2023). Literature study: Utilization of the PjBL model in science education to improve creativity and critical thinking skills. *Jurnal Penelitian Pendidikan IPA*, *9*(1), 133–143. https://doi.org/10.29303/jppipa.v9i1.2555

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