Available Online at www.e-iph.co.uk
Indexed in Clarivate Analytics WoS, and ScienceOPEN

E-B
Environment - Behaviour
Proceedings Journal

NSSEC-24

https://sites.google.com/view/nssec-24/home

National Social Sciences & Education Conference

06-07 July 2024
Virtual conference organized by CLM Publishing

Fostering STEM Education in Primary Schools: A Review of strategies for enhancing science skills, design thinking, and inquiry-based learning

Mohd Yahya Fadzli Jusoh[1], Nor Asniza Ishak[1*], Rendi Restiana Sukardi[2], Wiwit Artika[3], Asnida Ismail[4]
*Corresponding Author

[1] School of Educational Studies, Universiti Sains Malaysia, Penang, Malaysia
[2] Cibiru Campus of Universitas Pendidikan Indonesia, Cibiru Wetan, Bandung, West Java, Indonesia
[3] Biology Education Department, Faculty of Education and Teacher Training, Universitas Syiah Kuala, Aceh, Indonesia
[4] Institute of Teacher Education Pulau Pinang Campus, Penang, Malaysia

fadmy29@gmail.com, asnizaishak@usm.my, rendisukardi@upi.edu ,wartika@usk.ac.id, asnida2512@gmail.com
Tel: +60166630644

Abstract
This systematic literature review investigates strategies and findings to enhance science process skills, design thinking, and inquiry-based learning in primary education. By analyzing 9 Web of Science and Scopus databases articles, the review identifies successful pedagogical approaches, the role of technology-rich environments and scaffolding strategies, and the impact of individual differences in developing these skills. The results highlight the effectiveness of innovative pedagogy, technology-rich environments, scaffolding, and differentiated instruction. However, the review also reveals research gaps, such as the need for long-term studies, exploring the effectiveness of technology-rich environments and scaffolding strategies in the leading science program, and assessing differentiated teaching and guidance strategies.

Keywords: Differentiated instruction, scaffolding strategies, scientific inquiry, STEM education

DOI: https://doi.org/10.21834/e-bpj.v9iSI20.6093

1.0 Introduction

Enhancing science process skills, design thinking, and Inquiry-Based Learning (IBL) in primary education is crucial for developing students' critical thinking, problem-solving abilities, and scientific understanding (Aulia et al., 2023) Traditional teaching methods often fail to adequately foster these essential skills. Effective Science, Technology, Engineering, and Mathematics (STEM) education should seamlessly integrate technology, engineering, and rigorous instruction in science and mathematics (Kelley & Knowles, 2016). IBL enhances students' skills and interest in science careers, promotes problem-solving and critical thinking, supports gifted students, and aligns with the demands of 21st-century skills (Sarnoko et al., 2024). A transdisciplinary STEM approach provides a comprehensive learning experience that is vital for preparing students for future success. Nevertheless, previous systematic literature reviews have highlighted gaps in the integration of design thinking, IBL, and science process skills, indicating a need for more comprehensive research in these areas (Razali et al., 2022); (Idris et al., 2022); (Putu et al., 2023).

This Systematic Literature Review (SLR) synthesizes and analyzes strategies to enhance inquiry-based learning, science process skills, and design thinking in primary education. It evaluates the effectiveness of these strategies, explores innovative pedagogical

DOI: https://doi.org/10.21834/e-bpj.v9iSI20.6093

approaches, and assesses the role of technology and individual differences. Effective implementation fosters critical thinking, problem-solving, and scientific understanding. Active teacher involvement ensures interactive, engaging learning environments that promote curiosity, exploration, and meaningful learning.

2.0 Literature Review

Design thinking, science process skills, and inquiry-based learning (IBL) are crucial for fostering essential 21st-century skills such as problem-solving, critical thinking, creativity, and innovation in primary education (Felix et al., 2023; Thornhill-Miller et al., 2023). Science process skills help students achieve a deeper understanding of scientific principles, while design thinking strengthens learning and promotes creativity, critical thinking, problem-solving, and innovative skills (Alashwal, 2020; Noel & Liub, 2016). IBL promotes interdisciplinary knowledge-building and higher-order thinking skills (Kopcha et al., 2017; Li et al., 2016)

Educational robotics and computational thinking are effective in preparing primary school learners to apply these skills in real-world scenarios (Katyetova, 2023; Shipepe et al., 2022). Incorporating these approaches into elementary school curricula is vital for the long-term success of STEM education (GULL et al., 2022) and developing critical skills essential for 21st-century success (Adeoye & Jimoh, 2023).

Despite their importance, inconsistent application, lack of resources, and insufficient teacher training hinder the effectiveness of design thinking, inquiry-based learning, and science process skills in primary education. This leads to unequal development in students' creativity, critical thinking, and scientific literacy (Baharom et al., 2020; Kurniawati, 2021; Sumantri, 2023; Widyaningsih et al., 2020; Yalçın, 2022). Standardized practices, adequate resources, and professional development are necessary, along with collaboration among educators, policymakers, and stakeholders to ensure effective integration and equip students for real-world challenges.

3.0 Methodology

This research used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Framework, which contains the Identification, Screening, and Eligibility phases (Page et al., 2021). The description is described in Sections 3.1, 3.2, 3.3, and 3.4 as follows:

3.1 Identification

The PRISMA methodology in systematic reviews involves three stages: identifying relevant keywords, generating search strings for databases like Web of Science (WoS) and Scopus, and selecting eligible publications (Arslan, 2020). These databases offer comprehensive coverage and tools compatible with bibliographic software, streamlining the research process. This step retrieved 55 research articles, as shown in Table 1.

Table 1. Search strings apply for SLR

Scopus	TITLE-ABS-KEY (("science process skill*" OR "scientific process skill*" OR "science inquiry skill*" OR "scientific inquiry skill*" OR "science thinking skill*" OR "scientific thinking skill*" OR "science skill*" OR "scientific skill*" OR "inquiry skill*") AND ("primary school*" OR "elementary school*" OR "primary education" OR "elementary education" OR "primary level" OR "elementary level" OR "grade 1" OR "grade 2" OR "grade 3" OR "grade 4" OR "grade 5" OR "grade 6" OR "year 1" OR "year 2" OR "year 3" OR "year 4" OR "year 5" OR "year 6") AND ("design thinking" OR "design-based learning" OR "problem-based learning" OR "inquiry-based learning" OR "project-based learning" OR "STEM education" OR "STEAM education" OR "active learning" OR "hands-on learning" OR "experiential learning"))
WoS	("science process skill*" OR "scientific process skill*" OR "science inquiry skill*" OR "scientific inquiry skill*" OR "science thinking skill*" OR "scientific thinking skill*" OR "science skill*" OR "scientific skill*" OR "inquiry skill*") AND ("primary school*" OR "elementary school*" OR "primary education" OR "elementary education" OR "primary level" OR "elementary level" OR "grade 1" OR "grade 2" OR "grade 3" OR "grade 4" OR "grade 5" OR "grade 6" OR "year 1" OR "year 2" OR "year 3" OR "year 4" OR "year 5" OR "year 6") AND ("design thinking" OR "design-based learning" OR "problem-based learning" OR "inquiry-based learning" OR "project-based learning" OR "STEM education" OR "STEAM education" OR "active learning" OR "hands-on learning" OR "experiential learning") (Topic)

For the second step, after identifying the search string, we applied filters to retrieve articles published within the last five years, focusing exclusively on journal articles. Additionally, we included articles published in 2019 and earlier. The researchers conducted a thorough screening process, evaluating the articles at the final level only. To ensure the most up-to-date information, the researchers submitted a database compiled on April 30, 2024, for review. Table 2 defined Inclusion and Exclusion criteria for the second step as follows:

Table 2. Inclusion and Exclusion Criteria

Criterion	Inclusion	Exclusion
Language	English	Non-English
Timeline	2020 – 2024)	< 2019
Literature type	Journal Article,	Book, Review, Conference Proceedings
Publication Stage	Final	In Press
Date of data obtained	(April 30, 2024)	

After applying the inclusion and exclusion criteria presented in Table 2, the researchers successfully identified 33 articles aligned with the criteria. These articles were then subjected to a subsequent screening process to identify and eliminate any redundant articles obtained from the two databases, namely Scopus and WoS.

3.2 Screening
Thorough data screening is crucial for maintaining systematic review accuracy. Articles are obtained from reliable databases like Scopus and Web of Science (Pranckutė, 2021). Multiple databases can result in duplicates, potentially introducing bias (António & Guilhermina Lobato, 2023). A strict protocol identifies and eliminates duplicates, keeping only the first instance (Amir et al., 2023). After removing duplicates, articles are assessed to meet inclusion and exclusion criteria, ensuring the studies' relevance and the review's integrity and quality (Pranckutė, 2021).

3.3 Eligibility
In the eligibility stage, 31 articles were screened for alignment with inclusion criteria and research objectives (Page, McKenzie, et al., 2021). Four reports were excluded due to unrelated abstracts. Two experts in Science and STEM Education, each with over a decade of experience, meticulously reviewed the articles for relevance. Ultimately, 9 articles were deemed suitable for inclusion in the review (refer to Figure 1). Based on 9 articles that have been filtered, all are grouped based on the following themes (1) Cultivating Scientific Inquiry, Design Thinking, and Process Skills Through Innovative Pedagogical Approaches, (2) Enhancing Science Process Skills Through Technology-Rich Environments and Scaffolding Strategies and (3) Addressing Individual Differences to Optimize the Development of Science Process Skills Through Inquiry-Based Learning. All of these themes will be discussed in the findings section.

3.4 Data Abstraction and Analysis

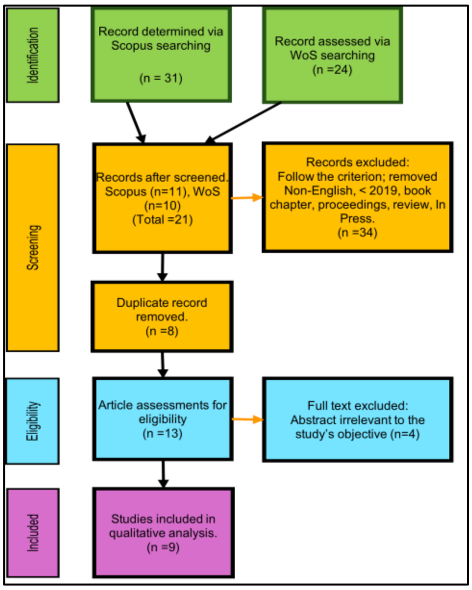

Fig. 1: Flow Diagram of the Proposed Searching Study
(Source: Moher D, Liberati A, Tetzlaff J, 2009)

4.0 Finding and Discussion
The development of science process skills, design thinking, and IBL has become increasingly important in primary education as it lays the foundation for students to become scientifically literate and equipped with the necessary skills to face the challenges of the 21st century. This SLR aims to highlight effective strategies, summarize research outcomes, identify gaps, discuss technological impacts, and provide recommendations to improve Inquiry-Based Learning, Science Process Skills, and Design Thinking in primary schools. Therefore, the findings and discussions focused on three main themes, namely (1) Cultivating Scientific Inquiry, Design Thinking, and Process Skills Through Innovative Pedagogical Approaches, (2) Enhancing Science Process Skills Through Technology-Rich Environments and Scaffolding Strategies and (3) Addressing Individual Differences to Optimize the Development of Science Process Skills Through Inquiry-Based Learning.

4.1 Theme 1: Cultivating Scientific Inquiry, Design Thinking, and Process Skills Through Innovative Pedagogical Approaches
The findings from the articles on this theme highlight the effectiveness of innovative pedagogical approaches in cultivating scientific inquiry, design thinking, and process skills in primary education. These approaches include open inquiry-based science laboratory practices (Ünlü et al., 2023), integrated STEM education (Ortiz-Revilla et al., 2021), and *Teoriya Resheniya Izobretatelskikh Zadatch*

(TRIZ), or "Theory of Inventive Problem Solving"-STEM activities customized about nanotechnology education (Cavdar et al., 2024). These approaches have shown promise in improving learning styles, scientific inquiry skills, science learning skills, as well as critical thinking dispositions among students and teacher candidates (see Figure 2 for a visual representation of the model).

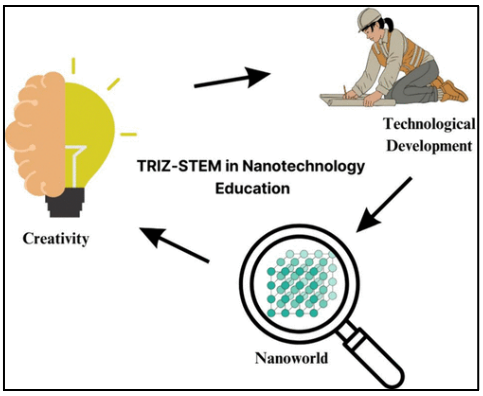

Figure 2: TRIZ Model
(Source: Cavdar et al., 2024)

On the other hand, research by Ortiz-Revilla et al. highlights the promising potential of integrated STEM education in fostering competence development among primary education students, which is especially noteworthy (see Figure 3 for a visual representation).

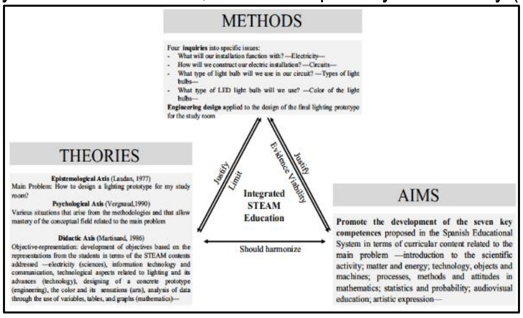

Figure 3: STEM Deductive Unit Model
(*Source:Ortiz-Revilla et al., 2021)*

However, the lack of significant effects of TRIZ-STEM activities concerning problem-solving, critical thinking, and research inquiry skills raises questions about the effectiveness of this approach and calls for further investigation. These innovative pedagogical approaches show promise in cultivating scientific inquiry, design thinking, and process skills, as well as promoting the development of essential skills and positive attitudes toward science and technology. Nevertheless, more research is needed to fully understand their impact and to identify best practices for their implementation in primary education settings.

4.2 Theme 2: Enhancing Science Process Skills Through Technology-Rich Environments and Scaffolding Strategies

The articles emphasize the importance of technology-rich environments and scaffolding strategies in enhancing science process skills and supporting Inquiry-Based Learning (IBL) in primary education. The use of digital technologies and IBL activities has been shown to contribute to meaningful learning of science subjects and the development of thinking skills (Inel-Ekici & Ekici, 2022; Kamarudin et al., 2024). Additionally, scaffolding strategies, particularly language scaffolding practices, have been found to support a holistic approach to IBL for novice learners (Langdon & Pandor, 2020). These findings highlight the potential of technology-rich environments and scaffolding strategies to enhance science process skills and support IBL experiences in primary education.

4.3 Theme 3: Addressing Individual Differences to Optimize the Development of Science Process Skills Through Inquiry-Based Learning

The articles on this theme explore the relationship between individual differences and learning outcomes in developing science process skills through IBL within primary education. The findings underscore the importance of considering individual differences when designing and implementing learning experiences to foster these skills. Moreover, engaging children with data science has been discovered to develop skills in citizenship education, positioning children as agents and advocates (Makar et al., 2023) and highlighting the potential of IBL to promote cross-disciplinary skills and empowerment. Nonetheless, the influence of individual differences, such as prior conceptual knowledge, academic abilities, and affective factors, on learning outcomes and learning processes in science and technology education (Makar et al., 2023) raises concerns about equity and inclusivity in developing science process skills through IBL. The use of supportive tools like video examples has been shown to have a positive influence on participants' inquiry behavior and skill development (Solé-Llussà et al., 2022), more research is needed to identify effective strategies for differentiated instruction and guidance that can optimize learning conditions for each student (as shown in Figure 4).

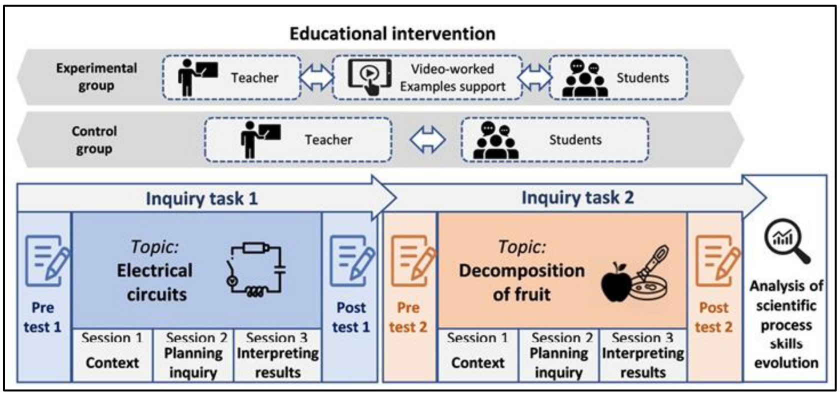

Figure 4: Employing Video-Based Worked Examples to Enhance Science Process Skills Among Elementary School Students
(Source:Solé-Llussà et al., 2022)

Future studies should also investigate the long-term impact of developing science process skills through IBL on students' academic and personal growth, as well as the potential barriers to implementation in diverse educational contexts.

5.0 Conclusion

This systematic literature review (SLR) explores strategies for enhancing science process skills, design thinking, and inquiry-based learning (IBL) in primary education, highlighting effective innovative pedagogical approaches. It identifies key areas for future research, including the long-term impacts on student growth, technology integration, and implementation challenges in diverse contexts. While focused on primary education, limiting generalizability to higher levels, the review provides valuable insights for refining educational practices to better prepare students for the complexities of the 21st century.

Acknowledgements

Thanks to the School of Educational Studies, Universiti Sains Malaysia, and other parties that support this valuable publication.

Paper Contribution to Related Field of Study

The paper's contribution can inspire future research on creative approaches for students in Science Process Skills, Design Thinking, and IBL approach in STEM education.

References

Adeoye, M. A., & Jimoh, H. A. (2023). Problem-solving skills among 21st-century learners toward creativity and innovation ideas. *Thinking Skills and Creativity Journal*, 6(1), 52–58. https://doi.org/10.23887/tscj.v6i1.62708

Alashwal, M. (2020). Design thinking in STEM education: A review. *International Research in Higher Education*, 5(1), 18. https://doi.org/10.5430/irhe.v5n1p18

Amir, H., Permatananda, P. A. N. K., Cahyani, D. D., Langelo, W., Rosita, R., Sajodin, S., Noprianty, R., Astuti, A., Suhari, S., Wahyuningsih, S., Kusumawati, P. D., Swamilaksita, P. D., Sudarman, S., & Syaiful, S. (2023). Enhancing skill conceptualization, critical thinking, and nursing knowledge through reflective case discussions: A systematic review. *Journal of Medicine and Life*, 16(6), 851–855. https://doi.org/10.25122/jml-2023-0042

António, F., & Guilhermina Lobato, M. (2023). Effects of using augmented reality on students' learning. *Trends in Computer Science and Information Technology, 8*(1), 001–004. https://doi.org/10.17352/tcsit.000061

Arslan, A. (2020). A systematic review on flipped learning in teaching English as a foreign or second language. *Dil ve Dilbilimi Çalışmaları Dergisi*, 16(2), 775–797. https://doi.org/10.17263/jlls.759300

Aulia, I., Sumah, A. S. W., & Genisa, M. U. (2023). Increasing science process skills using inquiry learning model. *Jurnal Pijar Mipa, 18*(3), 317–323. https://doi.org/10.29303/jpm.v18i3.4850

Baharom, M., Atan, N., Rosli, M., Yusof, S., & Hamid, M. (2020). Integration of science learning apps based on inquiry based science education (IBSE) in enhancing students' science process skills (SPS). *International Journal of Interactive Mobile Technologies (iJIM, 14)*(09), 95. https://doi.org/10.3991/ijim.v14i09.11706

Cavdar, O., Yıldırım, B., Kaya, E., & Akkus, A. (2024). Exploring the nanoworld: Middle school students use TRIZ-STEM in nanotechnology education. *Journal of Chemical Education*. https://doi.org/10.1021/acs.jchemed.3c01031

Felix, D., Kilag, O. K., Malbas, M., Catacutan, A., Tiongzon, B., & Abendan, C. F. (2023). Towards global competence: Innovations in the Philippine curriculum for addressing international challenges. *Excellencia: International Multi-Disciplinary Journal of Education*.

Gull, C., Levenson Goldstein, S., & Rosengarten, T. (2022). STEM learning and loose parts in early elementary classrooms: A scoping review. *International Online Journal of Primary Education, 11*(2), 279–292. https://doi.org/10.55020/iojpe.1201534

Inel-Ekici, D., & Ekici, M. (2022). Mobile inquiry and inquiry-based science learning in higher education: Advantages, challenges, and attitudes. *Asia Pacific Education Review, 23*(3), 427–444. https://doi.org/10.1007/s12564-021-09729-2

Kamarudin, M. Z., Mat Noor, M. S. A., & Omar, R. (2024). 'How do plants grow?': Teaching photosynthesis using digital inquiry-based science learning. *Science Activities, 61*(3), 118–131. https://doi.org/10.1080/00368121.2024.2315035

Katyetova, A. (2023). Development of algorithmic and programming thinking at primary school in state educational programs. *Trends in Education, 15*(1), 26–36. https://doi.org/10.5507/tvv.2023.001

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education, 3*(1), 11. https://doi.org/10.1186/s40594-016-0046-z

Kopcha, T. J., McGregor, J., Shin, S., Qian, Y., Choi, J., Hill, R. B., Mativo, J., & Choi, I. (2017). Developing an integrative STEM curriculum for robotics education through educational design research. *Journal of Formative Design in Learning, 1*(1), 31–44. https://doi.org/10.1007/s41686-017-0005-1

Kurniawati, A. (2021). Science process skills and its implementation in the process of science learning evaluation in schools. *Journal of Science Education Research, 5*(2), 16-20. https://doi.org/10.21831/jser.v5i2.44269

Langdon, A., & Pandor, J. M. (2020). An investigation of scaffolding strategies to support structured inquiry language teaching to novice learners in a primary school setting. *Language Value, 13*(1), 1–22. https://doi.org/10.6035/LanguageV.2020.13.1

Li, Y., Huang, Z., Jiang, M., & Chang, T.-W. (2016). The effect on pupils' science performance and problem-solving ability through Lego: An engineering design-based modeling approach. *Educational Technology and Society, 19*(3), 143–156. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85000716711&partnerID=40&md5=6b17113be0f0118649f0d1a862569c61

Makar, K., Fry, K., & English, L. (2023). Primary students' learning about citizenship through data science. *ZDM-Mathematics Education, 55*(5), 967–979. https://doi.org/10.1007/s11858-022-01450-7

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). PRISMA 2009 flow diagram. In *The PRISMA statement* (Vol. 6, p. 1000097).

Noel, L.-A., & Liu, T. L. (2016, June 25). Using design thinking to create a new education paradigm for elementary level children for higher student engagement and success. *DRS2016: Future-Focused Thinking*. https://doi.org/10.21606/drs.2016.200

Ortiz-Revilla, J., Greca, I. M., & Meneses-Villagrá, J. A. (2021). Effects of an integrated STEAM approach on the development of competence in primary education students (Efectos de una propuesta STEAM integrada en el desarrollo competencial del alumnado de Educación Primaria). *Journal for the Study of Education and Development, 44*(4), 838–870. https://doi.org/10.1080/02103702.2021.1925473

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., & Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews . *The BMJ, 372*. https://doi.org/10.1136/bmj.n71

Pranckutė, R. (2021). Web of Science (WoS) and Scopus: The titans of bibliographic information in today's academic world. *Publications, 9*(1), 12. https://doi.org/10.3390/publications9010012

Razali, N., Ali, N., Safiyuddin, S., & Khalid, F. (2022). Design thinking approaches in education and their challenges: A systematic literature review. *Creative Education*. https://doi.org/10.4236/ce.2022.137145

Idris, N., Talib, O., & Razali, F. (2022). Strategies in mastering science process skills in science experiments: A systematic literature review. *Jurnal Pendidikan IPA Indonesia*. https://doi.org/10.15294/jpii.v11i1.32969

Putu, I., Suryawan, P., Sudiarta, G., Suharta, G., Kritis, B., Matematis, M., Matematika, P., & Masalah, I. (2023). Students' critical thinking skills in solving mathematical problems: Systematic literature review. *Indonesian Journal Of Educational Research and Review*. https://doi.org/10.23887/ijerr.v6i1.56462

Shipepe, A., Uwu-Khaeb, L., De Villiers, C., Jormanainen, I., & Sutinen, E. (2022). Co-learning computational and design thinking using educational robotics: A case of primary school learners in Namibia. *Sensors, 22*(21). https://doi.org/10.3390/s22218169

Solé-Llussà, A., Aguilar, D., & Ibáñez, M. (2022). The effect of an instructional intervention based on the use of video-worked examples to promote elementary students' science process skills. *International Journal of Education in Mathematics, Science and Technology, 10*(3), 753–772. https://doi.org/10.46328/ijemst.2158

Sumantri, M. (2023). The influencing of inquiry-based learning on science conceptual understanding in terms of primary school's self-efficacy. *Jurnal Obsesi Jurnal Pendidikan Anak Usia Dini, 7*(3), 3627–3638. https://doi.org/10.31004/obsesi.v7i3.4618

Thornhill-Miller, B., Camarda, A., Mercier, M., Burkhardt, J. M., Morisseau, T., Bourgeois-Bougrine, S., Vinchon, F., El Hayek, S., Augereau-Landais, M., Mourey, F., Feybesse, C., Sundquist, D., & Lubart, T. (2023). Creativity, critical thinking, communication, and collaboration: Assessment, certification, and promotion of 21st-century skills for the future of work and education. *Journal of Intelligence*. https://doi.org/10.3390/jintelligence11030054

Ünlü, P., Hacieminoglu, E., & Yildiz, N. G. (2023). A "light bulb moment": Lab experiments enhancing novelty and critical thinking designed by future teachers. *Thinking Skills and Creativity, 50*. https://doi.org/10.1016/j.tsc.2023.101413

Widyaningsih, D., & Gunarhadi, G. (2020). Analysis of science process skills on science learning in primary school. *Jurnal Pendidikan Sains Indonesia, 5*(2), 89-100. https://doi.org/10.2991/assehr.k.200129.085

Yalçın, V. (2022). Design thinking model in early childhood education. *International Journal of Psychology and Educational Studies, 9*(1), 196-210. https://doi.org/10.52380/ijpes.2022.9.1.715