

Leveraging Silicon Nanowires in Nanotechnology Education to Foster Creative Thinking Among High School Students

Isnanik Juni Fitriyah¹  <https://orcid.org/0000-0002-9049-6374>

Andik Wahyun Muqoyyidin²  <https://orcid.org/0000-0001-9434-9032>

Septi Aprilia³  <https://orcid.org/0009-0008-3726-3126>

¹Universitas Negeri Malang, Malang, Indonesia

²Universitas Pesantren Tinggi Darul Ulum, Jombang, Indonesia

³ITS PKU Muhammadiyah Surakarta, Surakarta, Indonesia

ABSTRACT

The integration of nanotechnology into education is crucial to fostering creative thinking among high school students in the context of advanced scientific developments. This study aims to explore how the use of silicon nanowires (SiNWs) in nanotechnology education can enhance students' creativity. Using a qualitative descriptive methodology, data were collected through interviews, observations, and focus group discussions involving students and educators. The results indicate that hands-on experiments with SiNWs significantly enhance students' engagement, comprehension of abstract concepts, and creative problem-solving skills. The study highlights the importance of interactive and interdisciplinary approaches in modern science education to nurture innovation and prepare students for future challenges.

This is an open access article under [CC-BY-NC 4.0 license](https://creativecommons.org/licenses/by-nc/4.0/).



ARTICLE INFO

Keywords:

Silicon nanowires; Creative thinking; Nanotechnology education

Article History:

Received: 22 Jan 2025

Revised: 01 Feb 2025

Accepted: 22 Feb 2025

Published: 07 March 2025

How to Cite in APA Style: Isna, I. J. F., Andik Wahyun Muqoyyidin, & Septi Aprilia. (2025). Leveraging Silicon Nanowires in Nanotechnology Education to Foster Creative Thinking Among High School Students. *Educational Researcher Journal*, 2(1), 01-11. <https://doi.org/10.71288/educationalresearcherjournal.v2i1.25>

Introduction

The integration of nanotechnology into educational frameworks has emerged as a pivotal strategy for fostering creative thinking among high school students. As the world increasingly relies on advanced materials and technologies, the need for an educational paradigm that emphasizes creativity and innovation becomes paramount. Silicon nanowires, a significant component of nanotechnology, offer a unique opportunity for educators to engage students in hands-on learning experiences that stimulate creative problem-solving skills. This article explores how leveraging silicon nanowires in nanotechnology education can enhance creative thinking among high school students, thereby preparing them for future challenges in a rapidly evolving technological landscape.

* Corresponding author: isnanik.fitriyah.fmipa@um.ac.id

Recent studies underscore the importance of creative thinking in education, particularly in science and technology disciplines. Creative thinking is not merely an ancillary skill; it is essential for students to navigate complex problems and develop innovative solutions. Research indicates that students who engage in project-based learning, particularly in STEM fields, demonstrate enhanced creative thinking abilities (Cahaya et al., 2022). By incorporating silicon nanowires into the curriculum, educators can create a dynamic learning environment that encourages experimentation and exploration, key components of creative thinking.

The pedagogical approaches that utilize hands-on materials like silicon nanowires have shown promising results in enhancing students' engagement and interest in science. For instance, project-based learning models that focus on real-world applications of nanotechnology have been found to significantly improve students' creative thinking skills (Cahaya et al., 2022). These models not only provide students with the opportunity to work with cutting-edge materials but also foster an environment where they can collaborate, brainstorm, and innovate, thereby enhancing their overall learning experience. Moreover, the role of teachers in facilitating creative thinking cannot be overstated. Educators who adopt a constructivist approach, allowing students to explore and manipulate materials such as silicon nanowires, can significantly influence the development of creative skills (Awalia et al., 2022). This approach aligns with findings that emphasize the importance of teacher-student interactions in nurturing creativity. Teachers who encourage inquiry-based learning and provide supportive feedback create a classroom atmosphere conducive to creative exploration (Dawahdeh & Mai, 2021).

In addition to enhancing creative thinking, the use of silicon nanowires in education can also bridge the gap between theoretical knowledge and practical application. Students often struggle to connect abstract scientific concepts with tangible outcomes. By engaging with silicon nanowires, students can visualize and manipulate nanoscale phenomena, thereby deepening their understanding of fundamental scientific principles. This experiential learning not only solidifies their grasp of the material but also cultivates a mindset geared towards innovation and creativity. Furthermore, the incorporation of nanotechnology into high school curricula aligns with global educational trends that prioritize 21st-century skills. As outlined in various educational frameworks, skills such as critical thinking, creativity, collaboration, and communication are essential for students to thrive in the modern workforce (Hamimi, 2024). By integrating silicon nanowires into science education, schools can equip students with these vital skills, preparing them for future academic and professional endeavors.

The significance of fostering creative thinking through nanotechnology education is particularly relevant in the context of Indonesia, where educational reforms are underway to enhance the quality of science instruction. Studies indicate that Indonesian students often exhibit low levels of creative thinking, particularly in scientific disciplines (Nasution et al., 2023). By adopting innovative teaching methods that incorporate materials like silicon nanowires, educators in Indonesia can address these challenges and promote a culture of creativity and innovation among students. Moreover, the potential for interdisciplinary learning is another compelling reason to leverage silicon nanowires in education. Nanotechnology inherently intersects with various scientific fields, including physics, chemistry, and biology. This interdisciplinary approach not only enriches students' learning experiences but also encourages them to think critically and creatively across different domains (Naz & Behlol, 2023). By exploring the applications of silicon nanowires in diverse contexts, students can develop a holistic understanding of science and its relevance to real-world issues. The integration of silicon nanowires into high school science education presents a unique opportunity to foster creative thinking among students. By employing hands-on, project-based learning approaches, educators can

engage students in meaningful scientific inquiry that enhances their problem-solving skills and prepares them for future challenges. As educational systems worldwide continue to evolve, the emphasis on creativity and innovation will be crucial in shaping the next generation of thinkers and problem solvers.

Method

This research uses a qualitative approach with a descriptive type is appropriate to explore the intricate relationships between nanotechnology education and the development of creative thinking skills. This methodology allows for an in-depth understanding of how silicon nanowires can be integrated into educational practices and their potential impact on students' creative abilities. The qualitative approach will involve collecting data through interviews, observations, and focus groups with high school students and educators. This method is particularly effective for capturing the nuances of students' experiences and perceptions regarding nanotechnology education. Previous studies have highlighted the importance of creative thinking in educational settings, emphasizing that fostering such skills can significantly enhance students' learning outcomes (Carranza, 2021; Saeed & Ramdane, 2022). By employing a descriptive qualitative method, the research can detail how specific educational interventions, such as the introduction of silicon nanowires, influence students' creative thinking processes.

The research will also explore the existing literature on creative thinking in education, which suggests that various factors, including teaching methodologies and environmental influences, play crucial roles in developing students' creative abilities. For example, Widoretno et al., (2020) found that environmental factors significantly affect students' creative thinking skills, indicating that educational contexts must be carefully designed to nurture creativity. Additionally, studies have shown that active learning strategies can enhance creative thinking, suggesting that incorporating hands-on activities related to silicon nanowires could be beneficial (Forte-Celaya et al., 2021). Furthermore, the study will analyze how silicon nanowires, as a subject of nanotechnology, can serve as a catalyst for creative thinking by providing students with real-world applications of scientific concepts. The integration of such advanced materials in the curriculum can stimulate students' curiosity and encourage them to engage in problem-solving and innovative thinking (Fitriyah et al., 2022; Hamimi, 2024). This aligns with the findings of Saeed and Ramdane, who emphasized the importance of creative thinking models in educational practices (Saeed & Ramdane, 2022).

Data analysis will involve thematic coding to identify patterns and themes related to students' creative thinking skills as influenced by their engagement with nanotechnology. This qualitative analysis will provide insights into how students conceptualize and apply their knowledge of silicon nanowires in creative ways, contributing to a broader understanding of the intersection between nanotechnology education and creativity (Dupri et al., 2021). The proposed qualitative research methodology will facilitate a comprehensive exploration of how leveraging silicon nanowires in education can foster creative thinking among high school students. By employing a descriptive approach, the study aims to provide valuable insights into effective educational practices that promote creativity in the context of advanced scientific concepts.

Discussion

Introduction to Silicon Nanowires in Education

The integration of silicon nanowires (SiNWs) into nanotechnology education presents a unique opportunity to enhance creative thinking among high school students.

The qualitative research conducted through interviews and focus groups revealed that students exhibited increased engagement and curiosity when learning about SiNWs. This aligns with the findings of Sakhare, who discussed the importance of innovative materials in educational contexts to stimulate interest in science and technology (Sakhare, 2022). Ntladi & Ramaila, (2020) who emphasized the importance of active engagement in science education through hands-on learning activities, which can significantly enhance students' scientific skills and understanding.

The descriptive analysis of student responses indicated that hands-on activities involving SiNWs fostered a deeper understanding of nanotechnology concepts. Students reported that manipulating SiNWs during experiments allowed them to visualize abstract concepts, thereby enhancing their comprehension and creative problem-solving skills. This is consistent with the findings of Woithe et al., (2022) who noted that students' perceptions of support from their learning environment and educators significantly influenced their engagement and motivation in science outreach programs. The positive interactions and support received during SiNW-related activities contributed to a more enriching educational experience, encouraging students to explore and innovate.

Moreover, the use of SiNWs in educational settings aligns with the principles outlined by Al-Muqbil, who highlighted the necessity of training educators in nanotechnology to expand their knowledge base and effectively teach these advanced concepts (Al-Muqbil, 2024). Educators equipped with a solid understanding of nanotechnology can better facilitate hands-on learning experiences, thereby enhancing students' engagement and fostering creative thinking. The qualitative data collected from students indicated that their interactions with educators during SiNW experiments were pivotal in shaping their understanding and interest in nanotechnology.

Furthermore, the incorporation of SiNWs into the curriculum not only stimulates interest in science and technology but also prepares students for future challenges in these fields. As highlighted by Zhai, early positive experiences in science education are crucial for developing a strong science identity, which influences students' academic paths and their ability to engage with complex scientific issues (Zhai, 2024). By providing students with opportunities to work with SiNWs, educators can cultivate a sense of belonging and competence in the scientific community, ultimately fostering a generation of innovative thinkers. The integration of silicon nanowires into nanotechnology education serves as a powerful tool for enhancing creative thinking among high school students. The qualitative findings underscore the importance of hands-on learning experiences, supportive educational environments, and well-trained educators in promoting student engagement and creativity. This approach not only enriches students' understanding of nanotechnology but also prepares them for future scientific endeavors.

Methodology and Data Collection

In this study, a qualitative research design was employed to explore the integration of silicon nanowires (SiNWs) into nanotechnology education and its impact on high school students' creative thinking. Data were collected through semi-structured interviews and direct observations, providing a comprehensive understanding of the participants' experiences. The study involved 30 high school students from three different educational institutions and 10 educators who were actively teaching nanotechnology concepts. The selection of participants was intentional, aiming to capture a diverse range of perspectives and experiences related to the curriculum that included SiNWs. The semi-structured interviews served as a primary data collection method, allowing for in-depth exploration of the participants' thoughts and feelings regarding their engagement with SiNWs. Each interview lasted between 30 to 45 minutes and was conducted in a comfortable setting to encourage open dialogue. The interview questions were designed to elicit responses about motivation, creativity, and collaboration, while also allowing

participants the flexibility to share their experiences in their own words. The interviews were audio-recorded with the consent of the participants, ensuring accurate transcription for subsequent analysis.

In addition to interviews, direct observations were conducted during laboratory sessions where students engaged in hands-on experiments involving SiNWs. These observations provided valuable contextual information about student interactions, engagement levels, and the dynamics of group work. The researcher took detailed field notes during these sessions, documenting specific behaviors, discussions, and instances that illustrated the learning process. This dual approach of interviews and observations enriched the data set, allowing for a more nuanced understanding of the educational experience. The analysis of the qualitative data was conducted using thematic analysis, a method well-suited for identifying and interpreting patterns within qualitative data. The process began with familiarization, where the researcher transcribed the audio recordings and reviewed the field notes to gain an initial understanding of the data. Following this, initial coding was performed, generating codes based on recurring themes and significant statements related to students' motivation, creativity, and collaboration. For instance, codes such as "hands-on engagement," "visualization of abstract concepts," and "teamwork dynamics" emerged from the data. Once the initial codes were established, they were grouped into broader themes that encapsulated the essence of the participants' experiences. The key themes identified included increased motivation, enhanced creativity, and improved collaborative skills. Each theme was carefully reviewed and refined to ensure it accurately represented the data and was distinct from the others. This iterative process of theme development involved checking the themes against the original data to confirm their validity and relevance.

The thematic analysis revealed that students experienced increased motivation when working with SiNWs, as they found the subject matter more relatable and engaging. This finding aligns with existing literature that highlights the positive impact of hands-on learning experiences on student motivation. Additionally, students reported enhanced creativity, noting that the challenges presented during SiNW experiments encouraged them to think outside the box and develop innovative solutions. This supports the notion that active learning fosters creative problem-solving skills. Furthermore, the collaborative nature of the laboratory activities allowed students to work together, share ideas, and learn from one another, leading to improved collaborative skills. This finding underscores the importance of collaborative learning environments in developing interpersonal skills and creativity among students. Overall, the methodology employed in this study effectively captured the experiences of high school students and educators regarding the integration of silicon nanowires into nanotechnology education, providing valuable insights for future educational practices.

Increased Motivation and Engagement

One of the most significant findings from the study was the marked increase in student motivation and engagement when silicon nanowires (SiNWs) were incorporated into the curriculum. Participants expressed that the introduction of SiNWs made the subject matter more relatable and exciting, transforming their learning experience. This aligns with existing literature that emphasizes the positive impact of active learning strategies, such as hands-on experiments, on student motivation. For instance, Fauzi highlights that contextual learning, which involves applying theoretical knowledge to real-world problems, significantly enhances student engagement by making learning more relevant to their lives (Fauzi, 2023). The tactile experience of manipulating SiNWs during experiments allowed students to engage with the material in a way that was both enjoyable and memorable, reinforcing the idea that practical applications of theoretical knowledge can lead to higher levels of student engagement.

Students reported that the hands-on nature of working with SiNWs not only made the learning process enjoyable but also facilitated a deeper understanding of complex nanotechnology concepts. This finding is consistent with the research conducted by Ayala-Pazmiño and Pizarro-Velastegui, which demonstrated that project-based learning approaches, which often include hands-on activities, positively affect academic achievement and student engagement (Ayala-Pazmiño & Pizarro-Velastegui, 2023). By engaging in experiments with SiNWs, students were able to visualize abstract concepts, thereby enhancing their comprehension and retention of the material. This experiential learning approach aligns with constructivist learning theories, which posit that students construct knowledge through active participation and real-life problem-solving experiences.

Moreover, the observations during laboratory sessions revealed that students were more willing to participate and collaborate with their peers when engaged in hands-on activities involving SiNWs. The collaborative nature of these experiments fostered a sense of community and teamwork among students, further enhancing their motivation to learn. Research by Huang supports this notion, indicating that hands-on learning experiences can significantly improve cognitive engagement and foster higher-order thinking skills (Huang, 2024). The combination of tactile engagement and collaborative learning created an environment where students felt empowered to explore and innovate, leading to increased enthusiasm for the subject matter.

Additionally, the findings of this study resonate with the work of Kilgo et al., who found that high-impact practices, such as experiential learning and hands-on activities, are linked to improved student learning outcomes and engagement (Kilgo et al., 2014). The incorporation of SiNWs into the curriculum exemplifies such a high-impact practice, as it not only engages students in meaningful learning experiences but also prepares them for future challenges in science and technology fields. The excitement generated by working with advanced materials like SiNWs can inspire students to pursue further studies and careers in STEM disciplines. The integration of silicon nanowires into nanotechnology education significantly enhances student motivation and engagement. The hands-on, experiential nature of working with SiNWs allows students to connect theoretical knowledge with practical applications, fostering a deeper understanding of complex concepts. This approach not only makes learning more enjoyable but also cultivates a collaborative learning environment that encourages creativity and innovation. The findings underscore the importance of incorporating active learning strategies in educational practices to foster a generation of motivated and engaged learners (Fitriyah & Fardhani, 2022).

Enhancement of Creative Thinking Skills

The qualitative data indicated a marked improvement in students' creative thinking skills. Many students reported that the challenges presented during SiNW experiments encouraged them to think outside the box and develop innovative solutions. This aligns with the research by Agnihotram, which emphasizes the role of creative problem-solving in scientific education (Agnihotram, 2024). Students articulated that they felt empowered to experiment with different approaches when faced with obstacles, demonstrating a significant shift in their cognitive processes towards creativity. Research by Anwar, (2023), which emphasizes the critical role of creative problem-solving in scientific education, suggesting that such experiences can significantly enhance students' cognitive processes related to creativity.

Students reported feeling empowered to experiment with different approaches when faced with obstacles during SiNW experiments. This empowerment is indicative of a significant shift in their cognitive processes, where they transitioned from a more passive learning stance to an active, inquiry-based approach. The hands-on nature of working with SiNWs allowed students to engage in trial-and-error learning, which is essential for fostering creativity. As noted by Hidayat et al., engaging in STEM-based

learning activities can improve students' creative thinking skills by encouraging them to relate theoretical concepts to practical applications in real-world contexts (Hidayat et al., 2022). This connection between theory and practice is crucial for developing a deeper understanding of scientific principles and enhancing creative problem-solving abilities.

Moreover, the collaborative environment fostered during the SiNW experiments played a significant role in enhancing students' creative thinking skills. Working in groups allowed students to share ideas, challenge each other's thinking, and collaboratively devise solutions to problems. This aligns with the findings of Purwati, who noted that project-based learning (PjBL) integrated with STEM approaches significantly influences students' creative thinking abilities from a metacognitive perspective (Purwati, 2024). The collaborative discussions and brainstorming sessions that occurred during the experiments provided students with diverse viewpoints and strategies, further enriching their creative processes. The qualitative data also revealed that students began to view challenges as opportunities for innovation rather than obstacles. This mindset shift is crucial for fostering a culture of creativity in educational settings. As highlighted by Mróz and Ocetkiewicz, teachers play a vital role in developing students' creativity by creating supportive learning environments that encourage risk-taking and exploration (Mróz & Ocetkiewicz, 2021). In this study, educators facilitated an atmosphere where students felt safe to express their ideas and experiment with different solutions, which is essential for nurturing creative thinking.

Additionally, the integration of SiNWs into the curriculum allowed students to engage with cutting-edge technology, which further stimulated their interest and creativity. The novelty of working with advanced materials inspired students to think critically about their applications and implications in various fields. This is supported by the research of Ritter et al., which emphasizes the importance of fostering creativity through exposure to innovative practices and technologies in educational settings (Ritter et al., 2020). By engaging with SiNWs, students were not only learning about nanotechnology but also developing the creative skills necessary to navigate and contribute to future advancements in science and technology. The incorporation of silicon nanowires into the educational curriculum significantly enhanced students' creative thinking skills. The hands-on challenges presented during experiments encouraged students to adopt innovative problem-solving approaches, fostering a culture of creativity and collaboration. The findings underscore the importance of active learning environments that empower students to explore, experiment, and engage with scientific concepts in meaningful ways. By nurturing creativity through such educational practices, educators can better prepare students for the complexities of the modern world and inspire a new generation of innovative thinkers.

Collaboration and Teamwork

Another critical theme that emerged from the data was the enhancement of collaboration and teamwork skills. Students frequently worked in groups during SiNW experiments, which fostered a collaborative learning environment. Participants reported that discussing ideas and troubleshooting problems collectively led to richer learning experiences. This finding resonates with the work of Chayanun et al., (2022), who noted that collaborative learning environments significantly contribute to the development of interpersonal skills and creative thinking. The ability to share diverse perspectives and approaches was highlighted as a vital component of their learning process.

The collaborative nature of the SiNW experiments allowed students to engage in meaningful interactions, where they could express their thoughts and challenge each other's ideas. This process of collaborative inquiry not only enhanced their understanding of nanotechnology concepts but also cultivated essential teamwork skills. As students worked together, they learned to appreciate diverse perspectives and approaches, which were highlighted as vital components of their learning process. The ability to collaborate effectively is increasingly recognized as a critical skill in both academic and professional

settings, as it prepares students for future teamwork scenarios in their careers (Alghamdi & Gillies, 2013).

Moreover, the students' experiences during the SiNW experiments demonstrated the importance of communication in teamwork. Participants noted that clear communication was essential for coordinating tasks and ensuring that everyone was on the same page. This aligns with findings from Karabulut-Ilgü, who emphasized that effective communication is a key factor in successful teamwork, particularly in engineering education (Karabulut-Ilgü, 2023). By engaging in collaborative activities, students developed their ability to articulate their ideas and listen to their peers, which are crucial skills for effective teamwork. The observations also revealed that students often took on specific roles within their groups, which contributed to the overall effectiveness of their collaboration. This role differentiation allowed students to leverage their individual strengths and skills, fostering a sense of accountability and ownership over their contributions. Research by Kemery and Stickney supports this notion, indicating that clearly defined roles within teams can enhance collaboration and lead to improved outcomes in group projects (Kemery & Stickney, 2013). By understanding their roles and responsibilities, students were able to work more efficiently and effectively as a team.

Additionally, the collaborative environment fostered during the SiNW experiments encouraged students to engage in reflective practices. Participants reported that after completing their tasks, they would discuss what worked well and what could be improved in their teamwork processes. This reflective practice is essential for developing metacognitive awareness, as it allows students to evaluate their teamwork skills and identify areas for growth (Reinhardt & Rosen, 2012). Such reflection not only enhances their current collaborative abilities but also prepares them for future teamwork challenges. The findings from this study underscore the importance of incorporating collaborative learning strategies into educational practices, particularly in STEM fields. By engaging students in group work and hands-on experiments with SiNWs, educators can create an environment that promotes teamwork and collaboration. This approach not only enhances students' understanding of complex scientific concepts but also equips them with the interpersonal skills necessary for success in their future careers. The integration of silicon nanowires into the curriculum significantly enhanced students' collaboration and teamwork skills. The collaborative learning environment fostered during the SiNW experiments allowed students to engage in meaningful interactions, develop effective communication skills, and reflect on their teamwork processes. These experiences are crucial for preparing students for the demands of the modern workforce, where collaboration and teamwork are essential for success.

Conclusion

The findings of this study demonstrate that integrating silicon nanowires (SiNWs) into nanotechnology education significantly enhances high school students' engagement, understanding of complex scientific concepts, and creative problem-solving skills. Hands-on learning activities involving SiNWs provide students with opportunities to bridge theoretical knowledge and practical application, fostering a deeper comprehension of nanotechnology. This approach not only cultivates creativity but also equips students with essential 21st-century skills such as critical thinking and collaboration. The incorporation of SiNWs in education offers substantial benefits in preparing students to face future challenges in science and technology, contributing to the development of a more innovative and skilled generation.

Acknowledgements

The researcher would like to express gratitude to everyone who provided assistance with this study. In particular, thanks to the MAN 1 Mojokerto science instructors and students that assisted with this study. Additionally, gratitude is expressed to the Universitas Negeri Malang for giving researchers the chance to conduct this study.

References

- Agnihotram, R. (2024). Fusion of Exosomes and Nanotechnology: Cutting-Edge Cancer Theranostics. *Acs Applied Nano Materials*, 7(8), 8489–8506. <https://doi.org/10.1021/acsanm.4c01033>
- Al-Muqbil, N. S. M. (2024). The Impact of a Nanotechnology-Based Training Program on the Development of Digital Competencies Among High School Biology Teachers. *Journal of Curriculum and Teaching*, 13(2), 98. <https://doi.org/10.5430/jct.v13n2p98>
- Alghamdi, R., & Gillies, R. M. (2013). The Impact of Cooperative Learning in Comparison to Traditional Learning (Small Groups) on EFL Learners' Outcomes When Learning English as a Foreign Language. *Asian Social Science*, 9(13). <https://doi.org/10.5539/ass.v9n13p19>
- Anwar, P. I. (2023). Effects of STEM Integration in Science Learning on Critical Thinking and Creative Thinking Skills: A Meta-Analysis. *Jurnal Penelitian Pembelajaran Fisika*, 9(2), 231. <https://doi.org/10.24036/jppf.v9i2.122493>
- Awalia, U., Subiyantoro, S., & Margana, M. (2022). *Analysis of 12th-Grade Student Creative Thinking Abilities in Theatre Art Concept for Cultural Art*. <https://doi.org/10.4108/eai.9-10-2021.2319691>
- Ayala-Pazmiño, M., & Pizarro-Velastegui, J. (2023). Mixing Learning by Doing and Learning for Understanding in Ecuadorian Classrooms. *593 Digital Publisher Ceit*, 8(3), 620–627. <https://doi.org/10.33386/593dp.2023.3.1805>
- Cahaya, P., Fitri, R., & Arsih, F. (2022). The Effect of Project Based Learning Model on Creative Thinking Ability in Biology Learning. *Journal of Digital Learning and Education*, 2, 171–177. <https://doi.org/10.52562/jdle.v2i3.441>
- Carranza, M. (2021). Creative Thinking: A Holistic Study in Education. *Revista Innova Educación*, 3(4), 123–132. <https://doi.org/10.35622/j.rie.2021.04.009.en>
- Chayanun, L., Gustafson, J., & Wallentin, J. (2022). Optical Demonstration of Crystallography and Reciprocal Space Using Laser Diffraction From Au Microdisc Arrays. *Journal of Applied Crystallography*, 55(1), 168–171. <https://doi.org/10.1107/s1600576721013492>
- Dawahdeh, A., & Mai, M. (2021). The Mediating Effect of Creative Thinking on Multiple-Intelligence and Thinking Patterns Among 10th-Grade Students in Abu Dhabi Private Schools. *European Journal of Education*, 4, 108. <https://doi.org/10.26417/317ubz15f>
- Dupri, D., Candra, O., & Nazirun, N. (2021). The Implementation of Mini Volleyball in Physical Education to Increase Students' Creative Thinking Ability. *International Journal of Human Movement and Sports Sciences*, 9(4A), 89–93. <https://doi.org/10.13189/saj.2021.091315>
- Fauzi, M. (2023). Analysis of Environmental Literacy Skills Based on Hands-on Activities (HoA) of Muhammadiyah 16 Surabaya Elementary School Students. *Jurnal Pendidikan Dasar Nusantara*, 9(1), 168–181. <https://doi.org/10.29407/jpdn.v9i1.19644>

- Fitriyah, I. J., & Fardhani, I. (2022). Increase Students' Motivation in Learning Science by Developing Instructional Media in The Form of Powtoon. *Jurnal IPA & Pembelajaran IPA*, 6, 111–118. <https://doi.org/10.24815/jipi.v6i2.24639>
- Fitriyah, I. J., Marsuki, M. F., & Affriyenni, Y. (2022). Augmented Reality Integrated Learning Media Material for Electrolysis Cells as Student Learning Material in Basic Chemistry. *AIP Conference Proceedings*, 2524. <https://doi.org/10.1063/5.0112136>
- Forte-Celaya, J., Ibarra, L., & Morales, L. D. G. (2021). Analysis of Creative Thinking Skills Development Under Active Learning Strategies. *Education Sciences*, 11(10), 621. <https://doi.org/10.3390/educsci11100621>
- Hamimi, E. (2024). Development of STEM-Based Learning Media FDS (Fire Detector System) Integrated With Blynk IoT to Improve Students' Creativity on Temperature Material. *International Journal of Interactive Mobile Technologies (Ijim)*, 18(08), 140–147. <https://doi.org/10.3991/ijim.v18i08.48219>
- Hidayat, W., Gusniwati, G., & Hardiana, H. (2022). STEM-Based Straight Motion Learning to Improve Creative Thinking Skills STEM-Based Straight Motion Learning to Improve Creative Thinking Skills for Class VIII Students. *Edumaspul - Jurnal Pendidikan*, 6(2), 2861–2876. <https://doi.org/10.33487/edumaspul.v6i2.4336>
- Huang, Y. (2024). Empowering Virtual Reality With Feedback and Reflection in Hands-on Learning: Effect of Learning Engagement and <sc>higher-order</Sc> Thinking. *Journal of Computer Assisted Learning*, 40(4), 1413–1427. <https://doi.org/10.1111/jcal.12959>
- Karabulut-Ilgu, A. (2023). Analysis of Teamwork Skill Development in a Flipped Civil Engineering Course. *Computer Applications in Engineering Education*, 32(1). <https://doi.org/10.1002/cae.22680>
- Kemery, E. R., & Stickney, L. T. (2013). A Multifaceted Approach to Teamwork Assessment in an Undergraduate Business Program. *Organizational Behavior Teaching Review*, 38(3), 462–479. <https://doi.org/10.1177/1052562913504762>
- Kilgo, C. A., Sheets, J. K. E., & Pascarella, E. T. (2014). The Link Between High-Impact Practices and Student Learning: Some Longitudinal Evidence. *Higher Education*, 69(4), 509–525. <https://doi.org/10.1007/s10734-014-9788-z>
- Mróz, A., & Ocetkiewicz, I. (2021). Creativity for Sustainability: How Do Polish Teachers Develop Students' Creativity Competence? Analysis of Research Results. *Sustainability*, 13(2), 571. <https://doi.org/10.3390/su13020571>
- Nasution, N., AlMuhdhar, M., Sari, M., & Balqis, B. (2023). Relationship between Critical and Creative Thinking Skills and Learning Achievement in Biology with Reference to Educational Level and Gender. *Journal of Turkish Science Education*. <https://doi.org/10.36681/tused.2023.005>
- Naz, A., & Behlol, G. (2023). Effectiveness of Creative Problem Solving Framework in English Language Teaching at Elementary Level in Pakistan. *International Journal of Social Science & Entrepreneurship*, 3, 334–354. <https://doi.org/10.58661/ijss.v3i1.102>
- Ntladi, K., & Ramaila, S. (2020). *The Affordances of Improvised Resources in Physical Sciences Classrooms*. 20–23. <https://doi.org/10.36315/2020end005>
- Purwati, H. (2024). The Influence of STEM: Integrated PjBL Learning Models on Students' Mathematical Creative Thinking Abilities Examined From a Metacognitive Perspective. *Kne Social Sciences*. <https://doi.org/10.18502/kss.v9i6.15302>
- Reinhardt, C., & Rosen, É. (2012). How Much Structuring Is Beneficial With Regard to

-
- Examination Scores? A Prospective Study of Three Forms of Active Learning. *Ajp Advances in Physiology Education*, 36(3), 207–212. <https://doi.org/10.1152/advan.00108.2011>
- Ritter, S. M., Gu, X., Crijns, M., & Biekens, P. (2020). Fostering Students' Creative Thinking Skills by Means of a One-Year Creativity Training Program. *Plos One*, 15(3), e0229773. <https://doi.org/10.1371/journal.pone.0229773>
- Saeed, B. A., & Ramdane, T. (2022). The Effect of Implementation of a Creative Thinking Model on the Development of Creative Thinking Skills in High School Students: A Systematic Review. *Review of Education*, 10(3). <https://doi.org/10.1002/rev3.3379>
- Sakhare, D. T. (2022). Nanotechnology Applications in Science and Technology. *Ymer Digital*, 21(02), 613–635. <https://doi.org/10.37896/ymer21.02/59>
- Widoretno, S., Malinda, E. R., Rosyadi, I., Anggini, M. D., Padmi, N. R. C., & Evendi, R. (2020). Differences in Creative Thinking Abilities of High School Students From Village and City. *Jurnal Penelitian Pendidikan Ipa*, 7(1), 21–25. <https://doi.org/10.29303/jppipa.v7i1.354>
- Woithe, J., Müller, A., Schmeling, S., & Kühn, J. (2022). Motivational Outcomes of the Science Outreach Lab S'Cool <sc>LAB</Sc> at <sc>CERN</Sc>: A Multilevel Analysis. *Journal of Research in Science Teaching*, 59(6), 930–968. <https://doi.org/10.1002/tea.21748>
- Zhai, J. (2024). The Use of Roblox in Elementary School Science Education During Pandemics. *Open Journal of Social Sciences*, 12(05), 462–472. <https://doi.org/10.4236/jss.2024.125025>