JoSSEd
Journal of Science and Science Education
ISSN: 2774-1869 eISSN: 2774-2105

Improving Understanding of the Solar System Concept Through the Application of STEAM Assisted by Augmented Reality (AR) Media

Najwa Safina[1*], Fahmi Fatkhomi[1], Muriani Nur Hayati[1]

[1] Science Education Program, Faculty of Teacher Training and Education, Universitas Pancasakti Tegal, Tegal, Indonesia

Received: July 21, 2025
Revised: Janury 23, 2026
Accepted: April 16, 2026
Published: April 30, 2026

Corresponding Author:
Najwa Safina
najwasafina84@gmail.com

DOI: 10.29303/jossed.v7i1.12252

Abstract: Teachers struggle to explain abstract concepts, and a lack of supporting facilities in some schools also hinders the implementation of learning media. Low student engagement in learning can lead to misconceptions and a decline in conceptual understanding, which should be the foundation for knowledge acquisition. Therefore, students' understanding plays a crucial role in the learning process, which requires their ability to interpret meaning, master concepts, understand situations, and apply the facts they have learned. This study aims to determine the extent to which students' conceptual understanding increases in the solar system material by implementing STEAM learning assisted by Augmented Reality (AR) media in science learning. The method used is a quasi-experimental with a pretest-posttest control group design. With a purposive sampling technique, the sample was determined with class VII D as the experimental class and VII C as the control class. The instruments used included pretest-posttest questions and documentation, with data analysis carried out using SPSS version 26. The results showed that students' conceptual understanding in the experimental class reached 90.97% (very good category), while the control class was 76.94% (fairly good category). This study shows that the application of STEAM assisted by AR media has a positive impact, namely it is effective in improving students' conceptual understanding of the solar system.

Keywords: Augmented Reality (AR); Concept Understanding; Solar System; STEAM

Introduction

Education is an essential and inseparable part of human life (Bestari et al., 2023). The quality of education is a key factor in increasing human resource potential for a nation's progress (Sanga & Wangdra, 2023). In this context, through science learning, students are able to understand scientific knowledge and develop skills that can be useful in daily activities (Husna et al., 2022). Science learning aims to develop students' conceptual understanding and scientific thinking skills (Novita & Jumadi, 2022); (Elia et al., 2024). Furthermore, the science learning process also involves direct interaction with observed objects or events (Falloon, 2019). Data obtained from the PISA (Programme for International Student Assessment) indicates that mastery of concepts in science subjects is crucial in supporting individuals in achieving their life goals (Kwangmuang et al., 2021). However, conceptual understanding remains a significant issue in education, particularly in science learning (Siahaan & Sihotang, 2023). One contributing factor to this situation is conventional teaching and learning strategies and the minimal use of innovative media (Celsia Ditha Rahmani et al., 2025).

Interviews with junior high school science teachers revealed that solar system learning still predominantly relies on lectures and printed textbooks as the primary learning resources. However, solar system material is abstract and difficult to understand if presented solely verbally. Teachers struggle to explain abstract concepts, and the lack of supporting facilities in some schools also hinders the implementation of learning media (Haleem et al., 2022). This low level of student engagement can lead to misconceptions and a decline in conceptual understanding, which should be fundamental to knowledge acquisition (Vančugovienė et al., 2024). Therefore, students' understanding plays a crucial role in the learning process, which demands their ability to interpret meaning, master concepts, understand situations, and utilize the facts they have learned (Pols et

How to Cite:
Safina, N., Fatkhomi, F., & Hayat, M. N. (2026). Improving Understanding of the Solar System Concept Through the Application of STEAM Assisted by Augmented Reality (AR) Media. *Journal of Science and Science Education*, *7*(1), 9–15. https://doi.org/10.29303/jossed.v7i1.12252

al., 2021). Furthermore, understanding of science concepts is evident when students are able to re-express the content of lessons they have received based on their own reasoning and interpretation (Aidoo, 2024).

Amidst advances in digital technology, the use of technology in education has become a crucial and unavoidable aspect (Qazi et al., 2023). Furthermore, digital technology advancements have brought changes to education, creating more adaptive and innovative learning processes. With technological advancements, technological learning models such as Augmented Reality (AR) offer a new approach that allows students to visualize three-dimensional objects realistically in the learning environment (Crogman et al., 2025). AR can bridge the gap between abstract concepts and concrete understanding through interactive, real-time visualizations (Al-Ansi et al., 2023).

The STEAM learning approach can strengthen students' cognitive processes by integrating science, technology, engineering, art, and mathematics into a holistic learning experience (Priyatno, 2024). The STEAM approach, aided by Augmented Reality (AR), stimulates students' creative thinking and supports them in connecting theoretical understanding with its application in real life (AlAli et al., 2025). Therefore, this study aims to determine the extent to which students' conceptual understanding improves in the solar system material by implementing the STEAM learning model assisted by Augmented Reality (AR) in science learning.

Method

The research method used was experimental. This type of research is quasi-experimental. The design used in this study was a pretest-posttest control group design. This can be seen in Table 1.

Table 1. Pretest-Posttest-Control Group Design

Group	Pre-Test	Independent Variables	Post-Test
Experimental Class	Yb	X_1	Yes
Control Class	Yb	X_2	Yes

This research was conducted in a junior high school during the 2024/2025 academic year. The population was seventh-grade students. The sample was obtained using a purposive sampling technique based on student pre-test scores. The sample consisted of 31 students from classes VII C and VII D. The indicators of conceptual understanding measured in this study were: interpreting; classifying; comparing; and explaining. The data collection technique used a multiple-choice conceptual understanding test and documentation. The data collected consisted of pretest and posttest scores and student answers. Initial data analysis involved validating the learning tools. The conceptual understanding test instrument was then validated by an expert validator before being pilot tested in a class that had previously used the material, namely, eighth-grade students. Validity, reliability, difficulty level, and discriminatory power were then tested, resulting in 20 valid and suitable questions for use in the study.

The prerequisite analysis tests include the normality test using the Shapiro-Wilk method and the homogeneity test, both of which are analyzed with the help of IBM SPSS Statistics 26 software. The conclusion on the normality test is obtained by comparing the significance value (sig./P-Value) to the significance limit $\alpha = 0.05$. Similarly, the decision on the homogeneity test is determined by comparing the sig./P-Value value with the same significance level. The final data analysis technique is to conduct a hypothesis test using the N-Gain test and the independent sample t-Test.

Results and Discussion

This study aimed to determine the improvement in students' conceptual understanding in an experimental class using STEAM with Augmented Reality (AR) and a control class using STEAM without AR. Student conceptual understanding was measured based on conceptual understanding indicators (Salim Nahdi & Gilar Jatisunda, 2020); (Putri & Saehana, 2021). To analyze this improvement, the N-Gain test was used, which was then supported by statistical analysis using an independent sample t-test to determine the significance of the difference in improvement between the two groups. The results of the analysis of the average improvement in students' conceptual understanding in the experimental class (STEAM with AR) and the control class (STEAM without AR) are shown in Tables 2 through 7.

Table 2. Pretest-Posttest Results for the Control and Experimental Classes

Questions	Control	Experiment
Pretest	57.42	66.61
Posttest	76.94	90.97

The data analyzed were obtained through a pretest, intended to assess students' basic knowledge before implementing Augmented Reality (AR)-assisted STEAM learning. The pretest results, presented in Table 2, identified that the average score for students in the control class was 57.42, while the average score for the experimental class was 66.61. After the treatment, improvements were observed in both groups, with posttest scores shown in Table 2. The control class's score increased to 76.94, while the experimental class's score increased significantly to 90.97. Therefore, the learning strategies implemented in the experimental class were more effective in improving conceptual understanding than in the control class. These results align with findings from other studies that suggest the use of AR technology can improve student learning outcomes, particularly in conceptual understanding (Hermawan & Hadi, 2024).

One factor influencing the development of students' conceptual understanding is STEAM learning and the use of AR media. This is supported by other research that has shown that the use of AR learning media can effectively improve students' comprehension (Larasati & Widyasari, 2021). This is because STEAM learning is an effective learning model that can hone students' competencies, encouraging the use of technology and critical thinking skills to solve existing problems (Golden, 2023). This aligns with research showing that the use of AR media with learning models in education leads to students gaining more meaningful understanding, thereby retaining learned concepts in long-term memory (Di Filippo et al., 2025); (Atkinson et al., 2021).

Table 3. Pretest and posttest results per concept understanding indicator

Indicator	Control	Experiment	Control	Experiment
Interpreting	58.70	67.73	80	89.67
Classifying	46.77	46.77	66.93	81.14
Comparing	70.15	85.47	84.67	96.77
Explaining	56.22	66.85	84.67	94.75

Analysis of the results obtained from the pretest and posttest on each indicator of conceptual understanding was carried out to determine the level of student knowledge during the implementation of STEAM learning supported by AR media. This analysis used four indicators based on Bloom's taxonomy. Pretest and posttest data per indicator in the control class and the experimental class are shown in Table 3, namely there was an increase in the average score on each indicator between the pretest and posttest results in both classes, both the control and experimental classes. However, here there was an increase that occurred in the experimental class showed higher consistency. In the interpreting indicator, the experimental class's score increased from 67.73 to 89.67, while the control class from 58.7 to 80. For the classifying indicator, the experimental class experienced an increase from 46.77 to 81.14, while the control class from 46.77 to 66.93. The comparing indicator also showed an increase, namely from 85.47 to 96.77 in the experimental class, and from 70.15 to 84.67 in the control class. Meanwhile, the indicators explained that the experimental class's score increased from 66.85 to 94.75, and the control class's score from 56.22 to 84.67.

These data indicate that AR-assisted STEAM learning has proven effective in improving students' conceptual understanding across all indicators compared to the STEAM control class without AR. The experimental class's results were higher than those of the control class because the AR visualizations supported exploration and observation, helping students understand solar system concepts more comprehensively and engagingly. This is supported by other research that suggests that the use of AR technology can improve student learning outcomes while making the learning process more engaging and enjoyable (Zaid et al., 2022). These findings align with research demonstrating the importance of interdisciplinary integration and technology utilization in the STEAM approach (Yim et al., 2024); (Singh et al., 2024).

Table 4. Results of Normality Tests for Control and Experimental Classes

Indicator	Control Pretest	Experiment Posttest	Control Pretest	Experiment Posttest
Statistic	.984	.970	.993	.980
df	31	31	31	31
Sig.	.911	.530	.999	.823

The next data was analyzed through a normality test, which the study used the Kolmogorov-Smirnov method with the help of SPSS version 26. Data is said to be normally distributed if the significance value is > 0.05, conversely, if the significance value is < 0.05, the data is considered not normally distributed. Referring to Table 4, the results of the normality test for the experimental class and the control class show that the significance value is > 0.05. Thus, the data in both classes can be said to be normally distributed.

Table 5. Results of the Homogeneity Test for the Control Class and the Experimental Class

Levene Statistic	df1	df2	Sig.
2.368	1	60	.129

The next analysis is the homogeneity test, which is performed after the data is deemed normally distributed. This test is intended to identify whether there is equality of variance between groups. Data are considered homogeneous if the significance value is

>0.05, with a significance level of α = 0.05 (5%). Based on Table 5, the results of the homogeneity test for the experimental and control classes show a significance value of 0.129. Because this value is >0.05, it can be concluded that the data are homogeneous.

Table 6. n-Gain sore test for the control and experimental classes

	Experimental Class	Control Class
Average	0.75	0.46
Minimum	.40	.14
Maximum	1.00	1.00
Category	High	Moderate
Effectiveness Category	Effective	Less Effective

The next analysis was the N-Gain test, which aims to identify the effectiveness of AR-assisted STEAM implementation. Table 6 shows that the average score in the experimental class was higher than that of the control class. The experimental class achieved an average score of 0.75, categorized as effective, while the control class achieved an average score of 0.46, categorized as moderately effective, consistent with the interpretation (Wahab et al., 2021).

Table 7. Independent Sample T-Test for Control and Experimental Classes

	F	Sig.	T	Df	Sig. (2-tailed)
Concept Understanding	12.36	.000	7.177	60	.000

The next analysis was an independent sample t-test, which was used to determine the average difference in learning outcomes, particularly in conceptual understanding, between the experimental and control classes. Table 7 shows that the results of the independent sample t-test indicate a significant increase in conceptual understanding between the two classes (2-tailed significance = 0.000 < 0.05). Based on this value, it can be concluded that AR-assisted STEAM learning is more effective than AR-assisted STEAM learning. STEAM learning aims to instill skills relevant to 21st-century demands in students that can be applied across disciplines. STEAM is an approach that combines elements of art into the realm of science, technology, engineering, and mathematics (STEM), aiming to shift the learning paradigm to be more integrated and creative (Bertrand & Namukasa, 2020). Of these five elements, in the science field, it helps students learn the solar system in a more meaningful and relevant way. This aligns with findings showing that STEAM learning is effective in improving students' understanding of scientific concepts, including the Solar System (Arpaci et al., 2023).

From the technology side, the use of digital technology, such as AR learning media, plays a role in facilitating students' understanding and exploration of abstract concepts like the solar system. This is supported by research identifying the effectiveness and efficiency of AR media in conveying complex material to students (Radu et al., 2023). From the engineering side, through discussions, students design models of the solar system's structure and planetary orbits. The STEAM approach, supported by AR media, opens up opportunities for them to explore new ideas and creative solutions when solving challenges, such as building planetary models (Kajzer Mitchell & Walinga, 2017). From the arts side, students can channel their creativity through designing solar system structures and orbits. This finding is consistent with research findings that reveal that artistic activities can stimulate creative expression, train fine motor skills, and foster imagination in the form of visual works (Purwati et al., 2024).

Finally, in mathematics, students engage in calculation activities related to the solar system, such as comparing planetary diameters and calculating time differences between regions. This is supported by research evidence that STEAM learning with AR has the potential to stimulate increased critical thinking, creativity, and collaboration skills in completing math assignments (Nindiasari et al., 2024). Although STEAM learning with AR is unfamiliar to most students, many acknowledge that the approach significantly helps them understand the solar system more easily. Therefore, implementing a STEAM approach with AR has been shown to improve understanding of solar system concepts. When STEAM is combined with AR, students not only gain an interactive and visual learning experience but also more easily understand the structure, position, and movement of celestial objects in a realistic three-dimensional format.

This is supported by other research suggesting that AR can be a solution to the limitations of teaching aids, which often hinder the solar system learning process, by providing similar, or even more interactive, visualization functions (Fatma et al., 2021). Furthermore, the use of learning media can be an effective alternative to streamline the learning process (Fatkhomi & Widiyanto, 2025). Thus, the combination of STEAM and AR creates a more engaging learning environment and can increase student engagement and conceptual understanding of the solar system. Furthermore, AR media significantly contributes to overcoming challenges related to visualizing abstract concepts, such as astronomical phenomena, which are often difficult to grasp in conventional classrooms (Putra et al., 2024). Based on the results obtained, AR-assisted STEAM learning encourages students to connect mathematical concepts with real-world contexts and understand the role of mathematics in explaining natural phenomena. This approach also fosters critical thinking and problem-solving skills by utilizing the integration of the five main elements of STEAM (Rahmawati et al., 2019). These results are consistent with previous findings that revealed that the STEAM approach improves understanding of science concepts through student engagement (Maričić et al., 2025).

Conclusion

Based on the results of the analysis and discussion, it can be concluded that conceptual understanding in the experimental class that uses STEAM implementation with AR media has increased compared to the control class that uses STEAM learning without the help of AR media. This can be seen based on data showing that the experimental class obtained higher and more effective results than the control class. With an average posttest score in the experimental class reaching 90.97% (very good category), while the control class was 76.94% (fairly good category) in student conceptual understanding. Thus, it can be concluded that the application of STEAM assisted by AR media has a positive impact, namely being effective in increasing students' conceptual understanding of the solar system.

Acknowledgments
The author would like to express his gratitude to all those who provided support and contributions during the preparation of this article. He hopes this article will be useful and contribute to the development of science, particularly in the field of science education.

Author Contributions
Conceptualization; N. S.; methodology.; F. F.; validation; formal analysis; M. N. H.; investigation.; N. S; resources; M. N. H.; data curation: F. F.; writing—original draft preparation. N. S.; writing—review and editing: E.; visualization: F. F. All authors have read and agreed to the published version of the manuscript.

Funding
Researchers independently funded this research.

Conflicts of Interest
The authors declare no conflict of interest.

References

Aidoo, B. (2024). A reflective study on adopting inquiry-based science teaching methods. *Disciplinary and Interdisciplinary Science Education Research*, *6*(1). https://doi.org/10.1186/s43031-024-00119-3

AlAli, R., Wardat, Y., Zaki Aboud, Y., & Alhayek, K. A. (2025). The effectiveness of using augmented reality technology in science education to enhance creative thinking skills among gifted eighth-grade students. *Eurasia Journal of Mathematics, Science and Technology Education*, *21*(6), em2644. https://doi.org/10.29333/ejmste/16416

Al-Ansi, A. M., Jaboob, M., Garad, A., & Al-Ansi, A. (2023). Analyzing augmented reality (AR) and virtual reality (VR) recent development in education. *Social Sciences & Humanities Open*, *8*(1), 100532. https://doi.org/10.1016/j.ssaho.2023.100532

Arpaci, I., Dogru, M. S., Kanj, H., Ali, N., & Bahari, M. (2023). An Experimental Study on the Implementation of a STEAM-Based Learning Module in Science Education. *Sustainability*, *15*(8), 6807. https://doi.org/10.3390/su15086807

Atkinson, A. L., Allen, R. J., & Waterman, A. H. (2021). Exploring the understanding and experience of working memory in teaching professionals: A large-sample questionnaire study. *Teaching and Teacher Education*, *103*, 103343. https://doi.org/10.1016/j.tate.2021.103343

Bertrand, M. G., & Namukasa, I. K. (2020). STEAM education: Student learning and transferable skills. *Journal of Research in Innovative Teaching & Learning*, *13*(1), 43–56. https://doi.org/10.1108/jrit-01-2020-0003

Bestari, P., Awam, R., Sucipto, E., Marsidin, S., & Rifma, R. (2023). Peran Supervisi Pendidikan dalam Meningkatkan Kualitas Pembelajaran di Era Digital. *Jurnal Papeda: Jurnal Publikasi Pendidikan Dasar*, *5*(2), 133–140. https://doi.org/10.36232/jurnalpendidikandasar.v5i2.4016

Celsia Ditha Rahmani, Adrias Adrias, & Fadilla Suciana. (2025). Penggunaan Media Pembelajaran Berbasis Teknologi dalam Pembelajaran IPAS di Sekolah Dasar. *Sinar Dunia: Jurnal Riset Sosial Humaniora Dan Ilmu Pendidikan*, *4*(1), 268–278. https://doi.org/10.58192/sidu.v4i1.3193

Crogman, H. T., Cano, V. D., Pacheco, E., Sonawane, R. B., & Boroon, R. (2025). Virtual Reality, Augmented Reality, and Mixed Reality in Experiential Learning: Transforming Educational Paradigms. *Education Sciences*, *15*(3), 303. https://doi.org/10.3390/educsci15030303

Di Filippo, F., Pasquale, M., De Biasi, G., Faiella, F., Amboni, M., & Viggiano, A. (2025). The most effective way to obtain long-term memory is to increase first presentation duration of single words. *Cogent Education*, *12*(1). https://doi.org/10.1080/2331186x.2025.2498864

Elia, R., Solfema, S., Miaz, Y., & Zen, Z. (2024). Improving Concept Understanding and Learning Outcomes of Elementary School Students through Science Textbooks Based on Learning Cycle 7E Model. *Jurnal Penelitian Pendidikan IPA*, *10*(7), 4433–4441. https://doi.org/10.29303/jppipa.v10i7.7662

Falloon, G. (2019). Using simulations to teach young students science concepts: An Experiential Learning theoretical analysis. *Computers & Education*, *135*, 138–159. https://doi.org/10.1016/j.compedu.2019.03.001

Fatkhomi, F., & Widiyanto, B. (2025). Integrasi Padlet dalam Praktikum Fisika Dasar: Strategi Penguatan Literasi Digital Mahasiswa Pendidikan IPA. *PSEJ (Pancasakti Science Education Journal)*, *10*(1), 58–65. https://doi.org/10.24905/psej.v10i1.167

Fatma, Y., Salim, A., & Hayami, R. (2021). Augmented Reality Berbasis Android Sebagai Media Pembelajaran Sistem Tata Surya. *Jurnal CoSciTech (Computer Science and Information Technology)*, *2*(1), 53–59. https://doi.org/10.37859/coscitech.v2i1.2178

Golden, B. (2023). Enabling critical thinking development in higher education through the use of a structured planning tool. *Irish Educational Studies*, *42*(4), 949–969. https://doi.org/10.1080/03323315.2023.2258497

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

Hermawan, A., & Hadi, S. (2024). Realitas Pengaruh Penggunaan Teknologi Augmented Reality dalam Pembelajaran terhadap Pemahaman Konsep Siswa. *Jurnal Simki Pedagogia*, *7*(1), 328–340. https://doi.org/10.29407/jsp.v7i1.694

Husna, N., Halim, A., Evendi, E., Syukri, M., Nur, S., Elisa, E., & Khaldun, I. (2022). Impact of Science Process Skills on Scientific Literacy. *Jurnal Penelitian Pendidikan IPA*, *8*(4), 2123–2129. https://doi.org/10.29303/jppipa.v8i4.1887

Kajzer Mitchell, I., & Walinga, J. (2017). The creative imperative: The role of creativity, creative problem solving and insight as key drivers for sustainability. *Journal of Cleaner Production*, *140*, 1872–1884. https://doi.org/10.1016/j.jclepro.2016.09.162

Kwangmuang, P., Jarutkamolpong, S., Sangboonraung, W., & Daungtod, S. (2021). The development of learning innovation to enhance higher order thinking skills for students in Thailand junior high schools. *Heliyon*, *7*(6), e07309. https://doi.org/10.1016/j.heliyon.2021.e07309

Larasati, N. I., & Widyasari, N. (2021). Penerapan Media Pembelajaran Berbasis Augmented Reality Terhadap Peningkatan Pemahaman Matematis Siswa Ditinjau Dari Gaya Belajar. *Fibonacci: Jurnal Pendidikan Matematika Dan Matematika*, *7*(1), 45. https://doi.org/10.24853/fbc.7.1.45-50

Maričić, M., Anđić, B., Mumcu, F., Marić, M., Gordić, S., Gorjanac Ranitović, M., & Cvjetićanin, S. (2025). Enhancing student engagement through instructional STEAM learning activities and self-explanation effect. *Eurasia Journal of Mathematics, Science and Technology Education*, *21*(1), em2560. https://doi.org/10.29333/ejmste/15798

Nindiasari, H., Pranata, M. F., Sukirwan, S., Sugiman, S., Fathurrohman, M., Ruhimat, A., & Yuhana, Y. (2024). The use of augmented reality to improve students' geometry concept problem-solving skills through the STEAM approach. *Infinity Journal*, *13*(1), 119–138. https://doi.org/10.22460/infinity.v13i1.p119-138

Novita, R. R. & Jumadi. (2022). Students' Conceptual Understanding and Self-Directed Learning on Blended Learning. *Journal of Education Technology*, *6*(4), 617–624. https://doi.org/10.23887/jet.v6i4.49229

Pols, C. F. J., Dekkers, P. J. J. M., & De Vries, M. J. (2021). What do they know? Investigating students' ability to analyse experimental data in secondary physics education. *International Journal of Science Education*, *43*(2), 274–297. https://doi.org/10.1080/09500693.2020.1865588

Priyatno, S. (2024). Pengembangan e-Modul dengan pendekatan STEAM untuk meningkatkan kemampuan berpikir kreatif matematis siswa. *ANARGYA: Jurnal Ilmiah Pendidikan Matematika*, *6*(2), 149–158. https://doi.org/10.24176/anargya.v6i2.12028

Purwati, D., Astawan, I. G., & Antara, P. A. (2024). Enhancing Creative Imagination Ability in Early Childhood: A Study on Differential Learning Assisted with Loose Parts Media and Social Skills. *Jurnal Pendidikan Anak Usia Dini Undiksha*, *12*(1), 26–35. https://doi.org/10.23887/paud.v12i1.74007

Putra, M. A., Madlazim, M., & Hariyono, E. (2024). Exploring Augmented Reality-Based Learning Media Implementation in Solar System Materials. *IJORER : International Journal of Recent Educational Research*, *5*(1), 29–41. https://doi.org/10.46245/ijorer.v5i1.440

Putri, A. S., & Saehana, S. (2021). An analysis of students' conceptual understanding using STEM approach educational videos. *Journal of Physics: Conference Series*, *1760*(1), 012007. https://doi.org/10.1088/1742-6596/1760/1/012007

Qazi, A. G., Mustafa, M. Y., Mtenzi, F. J., & Valcke, M. (2023). Mobile Technology as an Alternative

Teaching Strategy Amidst COVID-19 Hiatus: Exploring Pedagogical Possibilities and Implications for Teacher Development. *Education Sciences*, *13*(4), 385. https://doi.org/10.3390/educsci13040385

Radu, I., Huang, X., Kestin, G., & Schneider, B. (2023). How augmented reality influences student learning and inquiry styles: A study of 1-1 physics remote AR tutoring. *Computers & Education: X Reality*, *2*, 100011. https://doi.org/10.1016/j.cexr.2023.100011

Rahmawati, Y., Ridwan, A., Hadinugrahaningsih, T., & Soeprijanto. (2019). Developing critical and creative thinking skills through STEAM integration in chemistry learning. *Journal of Physics: Conference Series*, *1156*, 012033. https://doi.org/10.1088/1742-6596/1156/1/012033

Salim Nahdi, D., & Gilar Jatisunda, M. (2020). Conceptual Understanding And Procedural Knowledge: A Case Study on Learning Mathematics of Fractional Material in Elementary School. *Journal of Physics: Conference Series*, *1477*(4), 042037. https://doi.org/10.1088/1742-6596/1477/4/042037

Sanga, L. D., & Wangdra, Y. (2023). Pendidikan Adalah Faktor Penentu Daya Saing Bangsa. *Prosiding Seminar Nasional Ilmu Sosial Dan Teknologi (SNISTEK)*, *5*, 84–90. https://doi.org/10.33884/psnistek.v5i.8067

Siahaan, F. E., & Sihotang, C. (2023). Pengaruh Model Pembelajaran Discovery Learning untuk Meningkatkan Pemahaman Konsep IPA Siswa SMP Satrya Budi Perdagangan. *Jurnal Simki Pedagogia*, *6*(1), 161–168. https://doi.org/10.29407/jsp.v6i1.233

Singh, M., Azad, I., Qayyoom, M. A., & Khan, T. (2024). A study on perceptions and practices of STEAM-based education with university students. *Social Sciences & Humanities Open*, *10*, 101162. https://doi.org/10.1016/j.ssaho.2024.101162

Vančugovienė, V., Södervik, I., Lehtinen, E., & McMullen, J. (2024). Individual differences in secondary school students’ conceptual knowledge: Latent profile analysis of biology concepts. *Learning and Individual Differences*, *111*, 102436. https://doi.org/10.1016/j.lindif.2024.102436

Wahab, A., Junaedi, J., & Azhar, Muh. (2021). Efektivitas Pembelajaran Statistika Pendidikan Menggunakan Uji Peningkatan N-Gain di PGMI. *Jurnal Basicedu*, *5*(2), 1039–1045. https://doi.org/10.31004/basicedu.v5i2.845

Yim, I. H. Y., Su, J., & Wegerif, R. (2024). STEAM in practice and research in primary schools: A systematic literature review. *Research in Science & Technological Education*, 1–25. https://doi.org/10.1080/02635143.2024.2440424

Zaid, M., Razak, F., & Alam, A. A. F. (2022). Keefektifan Media Pembelajaran Augmented Reality Berbasis STEAM dalam Meningkatkan Kualitas Pembelajaran IPA di Sekolah Dasar. *Jurnal Pelita: Jurnal Pembelajaran IPA Terpadu*, *2*(2), 59–68. https://doi.org/10.54065/pelita.2.2.2022.316