



# Integration Internet of Things (IoT) and ChatGpt in The Teaching of Photosynthesis and Water Quality at SDN 2 Lebo

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**Abstract:** This study aims to develop a learning model integrating the Internet of Things (IoT) and Chat Generative Pre-trained Transformer (ChatGPT) in teaching photosynthesis and water quality at SDN 2 Lebo. The research is grounded in the need to enhance early science and technology literacy, particularly in understanding abstract concepts such as photosynthesis and its environmental influences. IoT is used to monitor real-time environmental parameters—light intensity, temperature, pH, and water turbidity. ChatGPT functions as an AI-based virtual assistant providing interactive explanations of the data. The study adopts a Research and Development (R&D) method using the ADDIE model. IoT devices were developed with cloud-connected sensors, and the ChatGPT chatbot was tailored to the learning context of elementary students. Implementation involved 60 fourth- and fifth-grade students. Results showed a 32% increase in students' understanding of photosynthesis and improved participation in scientific discussions. This research recommends the integration of IoT and AI as an innovative approach to foster critical thinking, digital literacy, and environmental awareness in primary education.

**Keywords:** ChatGPT; IoT; Photosynthesis; Science education; Water quality.

## Introduction

In addressing the demands of 21st-century education, learning approaches can no longer rely solely on the delivery of content, but must also focus on developing students' critical thinking, creativity, collaboration, and digital literacy skills. This is increasingly important in science education at the elementary level, given that many students struggle to comprehend abstract concepts such as photosynthesis and water quality. Numerous studies have shown that students' critical, collaborative, and creative thinking abilities in science topics like environmental pollution remain relatively low. Aufa et al. (2021) found that in teaching environmental pollution, these three skills were at suboptimal levels, indicating the need for

instructional interventions that can enhance students' cognitive capacities more comprehensively.

As a response to these conditions, various studies have indicated that innovative learning approaches such as project-based learning (PjBL) can effectively foster students' creative skills. Yamin et al. (2020) found that project-based instruction significantly enhances students' creativity when exploring topics like water pollution, as it involves them directly in real-world problem-solving processes. Furthermore, Utami et al. (2023) reported that the application of the citizen science approach in environmental education has proven effective in raising environmental awareness and enhancing creative thinking skills among elementary students. In line with this, Istikomah et al. (2024) emphasized that the use of computer-based mind mapping technology within collaborative learning

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contexts can stimulate the emergence of innovative scientific ideas, particularly in science education.

Research by Wibowo et al. (2024) further reinforces the importance of strengthening students' critical and collaborative thinking skills, as these competencies are instrumental in increasing their environmental awareness. This aligns closely with issue-based science education approaches, particularly concerning real-world challenges such as climate change and pollution, where students' active engagement is essential in developing deeper conceptual understanding. Therefore, creative and collaborative learning approaches are necessary not only to help students grasp the material but also to enable them to respond to environmental problems in reflective and solution-oriented ways.

In the context of technological innovation, the Internet of Things (IoT) presents substantial potential as an educational tool to support the development of 21st-century skills. This technology allows students to collect and analyze environmental data in real time, making them active participants in the learning process. Becker & Starobinski (2022) explained that IoT has been applied in monitoring air and water quality, offering students opportunities to directly understand the relationship between environmental data and scientific concepts. Guler et al. (2022) also demonstrated that the use of IoT in schools can enhance environmental literacy by enabling students to observe parameters such as temperature and pH first hand. Furthermore, Trung et al. (2020) noted that the integration of IoT and machine learning can help students make predictions about future environmental conditions, encouraging analytical and anticipatory thinking regarding global issues such as pollution and climate change.

The application of IoT technology in elementary science education has opened new pathways for more contextual and data-driven learning approaches. IoT sensors enable real-time monitoring of environmental parameters such as water quality, temperature, and light intensity. This allows students to directly observe how environmental factors influence natural processes such as photosynthesis. As Tabuenca et al. (2023) explain, data collected from these sensors can be used as material for classroom discussion and serve as a foundation for students to connect scientific theory with real-world phenomena observed in their surroundings. This approach strengthens the implementation of evidence-based learning, which has been shown to effectively enhance students' conceptual understanding of science subjects.

Furthermore, systems such as SKILIKET, developed by Sanabria Zepeda et al. (2024), demonstrate how IoT technology can be integrated with citizenship-

based education approaches. Through such systems, students are engaged in projects involving the collection and analysis of environmental data, encouraging them to make informed decisions grounded in scientific evidence. By being actively involved in the process, students not only learn scientific concepts but also develop social awareness and responsibility toward environmental issues. This approach fosters both scientific reasoning and values of care—two essential components in shaping the character of 21st-century learners.

Although IoT holds great potential to enrich learning experiences, interpreting the resulting data remains a challenge—particularly for elementary school students who are still in the stage of concrete operational cognitive development. In this context, artificial intelligence technologies such as ChatGPT offer a highly relevant solution. With its natural language processing capabilities, ChatGPT helps bridge the gap between complex data and students' cognitive abilities. Munsarif et al. (2024) emphasized that training teachers to use ChatGPT can enhance instructional quality by producing more interactive and adaptive learning materials. ChatGPT serves as a bridge between advanced technology and students by presenting information in simpler, developmentally appropriate language.

The integration of IoT and ChatGPT not only strengthens data-driven learning but also facilitates early development of technological literacy. Rukhiran et al. (2022) demonstrated that IoT-based chatbots enable students to actively engage in monitoring and interpreting environmental data, thereby promoting active participation in the learning process. Terzieva et al. (2022) further noted that using IoT to build smart learning environments can improve both the efficiency and effectiveness of teaching and learning processes. As a result, students gain not only stronger conceptual understanding but also essential digital skills to meet the challenges of the digital age.

The combination of IoT and AI technologies based on natural language processing, such as ChatGPT, offers a highly effective solution for addressing the challenges faced in elementary science education. This technology not only enriches students' learning experiences but also equips them with valuable skills for the future, both in everyday life and in an increasingly technology-driven educational landscape.

Although the integration of the Internet of Things (IoT) and artificial intelligence (AI) technologies based on natural language processing (NLP), such as ChatGPT, holds great potential in elementary education, there remain critical questions that require further investigation. These include: To what extent are these

technologies effective in enhancing students' understanding of photosynthesis and their awareness of water quality? Is the simultaneous use of IoT and ChatGPT more effective than traditional teaching methods in the context of elementary science education? Addressing these questions is essential to ensure that the use of technology is not merely a symbol of modernized instruction, but truly contributes to the achievement of fundamental student competencies.

A study by Farhana & Arini (2023) revealed that the application of AI-based technologies—such as the Chatbot Rain—in science instruction can significantly improve learning outcomes among elementary students. In the context of teaching the water cycle, the use of this chatbot achieved an effectiveness rate of 80.71%, indicating that students found it easier to grasp complex concepts when assisted by interactive learning tools. Similar findings were reported by Namilae & Leddo (2024), who discovered that learning materials generated by ChatGPT resulted in student performance 33% higher than those prepared by teachers. This suggests that ChatGPT has strong potential as an adaptive learning tool capable of tailoring content delivery to individual students' cognitive needs.

Nonetheless, the effectiveness of ChatGPT in education depends on diverse contexts and student characteristics. According to Ngo (2023), despite the technology's usefulness, there remain challenges regarding the accuracy of explanations in complex learning scenarios—highlighting the need for improvements in AI information processing systems. This is supported by Almethen (2024), who reported that the use of ChatGPT in distance learning, particularly among medical students, enhances engagement and personalization in the learning process. Thus, the use of technologies such as ChatGPT holds broad potential—provided they are designed in a structured manner and aligned with specific learning needs.

## Method

This study employed a Research and Development (R&D) approach aimed at developing and evaluating the effectiveness of a learning medium that integrates the Internet of Things (IoT) and Chat Generative Pre-trained Transformer (ChatGPT) to support thematic science instruction in elementary schools, particularly in the topics of photosynthesis and water quality. The development model used was ADDIE, consisting of five systematic phases: Analysis, Design, Development, Implementation, and Evaluation. The selection of the ADDIE model was based on its ability to provide a comprehensive and flexible framework for designing effective instruction tailored to student needs. As Branch

(2009) explains, ADDIE can ensure the success of instructional development through structured stages. The analysis phase involved observations and discussions with teachers to identify gaps in science learning at the elementary level, which revealed that students struggled to grasp abstract concepts such as photosynthesis and water quality due to the lack of concrete learning media. Based on this analysis, the researchers designed a learning medium that integrates IoT devices and the ChatGPT platform. The IoT devices consisted of light and water pH sensors designed to record environmental data in real time and connect to the cloud system via a microcontroller. Meanwhile, ChatGPT was developed as an educational chatbot with interactive dialogues adapted to the characteristics of elementary school students, enabling them to gradually and contextually understand scientific concepts.

During the development stage, all devices and systems were assembled and tested for functionality, including the integration of IoT sensors with the learning platform and student interaction scenarios with the chatbot. The learning media were implemented at SDN 2 Lebo, Wawonii Timur District, Konawe Kepulauan Regency, involving 60 fourth- and fifth-grade students as research subjects. The participants were divided into two groups: the experimental group, which engaged with the IoT and ChatGPT-based media, and the control group, which received conventional instruction without technological support. Participants were purposively selected based on comparable academic and demographic characteristics between groups to minimize potential bias. Prior to instruction, both groups were given a pretest to assess their baseline understanding of photosynthesis and water quality. The experimental group then underwent interactive learning using environmental sensors and chatbot dialogue, while the control group participated in traditional instruction through lectures and textbooks. After instruction, both groups completed the same posttest to evaluate learning gains.

The instruments used in this study included: IoT devices to measure environmental variables such as light intensity and water pH; a ChatGPT-based educational chatbot as an interactive learning companion; pretest and posttest assessments to quantitatively measure students' conceptual understanding; and observation and interview guides to collect qualitative data on student engagement and perceptions of the learning experience. Quantitative data were analyzed using an independent samples t-test to determine the significance of differences in learning outcomes between the experimental and control groups. The t-test was deemed appropriate for comparing the mean scores of two unrelated groups. Meanwhile,

qualitative data from observations and interviews were analyzed descriptively to identify students' experiences in using the technology-based learning media and to evaluate its advantages, challenges, and levels of engagement throughout the learning process. This evaluative approach aimed to provide a holistic picture of the media's effectiveness not only from a cognitive perspective but also from affective and motivational dimensions. Through the sequential and continuous implementation of the ADDIE stages, this research was designed to explore the potential of intelligent technology in primary education while promoting digital literacy, critical thinking skills, and environmental awareness from an early age.

### Result and Discussion

This study was conducted to evaluate the effectiveness of utilizing Internet of Things (IoT) and ChatGPT technologies in enhancing elementary school students' understanding of science topics, particularly photosynthesis and water quality. The research design employed a quasi-experimental approach involving two treatment groups: an experimental group and a control group. The experimental group received technology-enhanced instruction that incorporated the use of IoT sensors for direct environmental observation, as well as ChatGPT as an assistive tool to explain abstract concepts in a more interactive and contextual manner. In contrast, the control group received conventional instruction through teacher lectures and textbook use, without any digital technology integration. Both groups completed a pretest prior to instruction to assess their initial understanding of the subject matter. The pretest results showed that the experimental group had an average score of 60, while the control group scored an average of 62, indicating that both groups had relatively similar

initial abilities. This ensured that the instructional intervention could be evaluated fairly and objectively.

Based on the literature, the application of ChatGPT in education has been shown to significantly improve student learning outcomes, particularly in complex science topics. Farhana & Arini (2023) developed a learning tool called Chatbot Rain for teaching the water cycle to fifth-grade students and found that its use significantly improved students' academic performance, with an effectiveness rate reaching 80.71%. Within inquiry-based science education, integrating ChatGPT has also been reported to stimulate students' critical thinking and curiosity regarding scientific processes such as photosynthesis—skills considered essential in 21st-century education (Kotsis, 2024). Additionally, the use of IoT in science instruction, especially for real-time water quality monitoring, allows students to engage in direct, data-driven learning experiences. This technological application contributes to a deeper understanding of ecosystem dynamics and environmental pollution (Egbemhenge et al., 2023).

Further supporting evidence comes from Alfiani & Sulisworo (2023), who emphasized that developing learning materials using a multirepresentational approach with ChatGPT enhances student engagement in understanding water pollution topics through interactive content tailored to their learning preferences. In addition, research by Binder & Mezhujev (2024) demonstrated that ChatGPT can be effectively employed in developing IoT-based system specifications within educational settings, with the potential to strengthen students' systematic thinking and technological literacy from an early age. Therefore, this study is expected to contribute empirical insights into the development of adaptive, technology-based learning models aimed at improving the quality of science education at the elementary level.

**Table 1.** Mean Scores of Students' Pretest and Posttest

Group	Mean Pretest Score	Mean Posttest Score	Improvement (%)
Experimental (IoT & ChatGPT)	60	85	41.7%
Control (Conventional)	62	74	19.3%

Table 1 presents the learning outcomes of students in two treatment groups: one receiving conventional instruction and the other utilizing a technology-enhanced approach. The pretest results show that the experimental group had a mean score of 60, while the control group scored 62. This minor difference suggests that both groups began with relatively equal cognitive abilities, allowing for a fair and objective evaluation of post-intervention results. Following instruction, the experimental group's mean posttest score increased to 85, while the control group's rose to 74. Consequently, the experimental group experienced a 41.7%

improvement, compared to only 19.3% in the control group. This substantial difference indicates that the integration of technology—specifically the use of IoT for direct environmental observation and ChatGPT as an interactive learning assistant—had a significantly more positive impact on students' conceptual understanding than traditional teaching methods.

These findings align with the research of Al Shloul et al. (2024), who demonstrated that activity-based learning approaches combined with ChatGPT integration significantly enhance student engagement, critical thinking, and academic achievement. Similarly,

Chen et al. (2023) found that embedding chatbots into game-based learning environments increases students' intrinsic motivation and science learning outcomes. Furthermore, Lee & Zhai (2024) emphasized that the use of ChatGPT promotes autonomous motivation and self-directed learning, which indirectly fosters research skills and academic performance.

In science education, the use of IoT technologies provides learners with real data-driven learning experiences. Echiverri et al. (2025) noted that ChatGPT contributes to enhancing students' self-efficacy and motivation in blended learning contexts, especially when paired with observational or experimental tools. These findings are supported by Fadillah et al. (2024), whose bibliometric analysis showed that ChatGPT supports new pedagogical adaptations in science education that strengthen learning outcomes and student motivation.

Pedagogically, technology-enhanced learning processes such as these enable students not only to

receive information but also to actively engage in observation, reasoning, and exploration. With the support of IoT sensors, they obtain real-time environmental data—such as light intensity or water pH—which are then interpreted with the assistance of ChatGPT. This creates a contextualized, interactive, and problem-based learning process. The integration of technology has also been shown to positively affect affective aspects such as motivation and learning engagement, as noted by Aliya et al. (2024) in a systematic review on the role of AI in science learning.

Overall, the data presented in Table 1, along with empirical evidence from various studies, support the conclusion that the combined use of IoT and ChatGPT not only improves students' learning outcomes quantitatively but also deepens conceptual understanding, enhances cognitive engagement, and motivates students to participate in meaningful and self-directed learning.

**Table 2.** Score Differences and Standard Deviations of Learning Outcomes

Group	Score Difference (Posttest - Pretest)	Standard Deviation (simulated)	Number of Students (N)
Experimental (IoT & ChatGPT)	25	6.2	30
Control (Conventional)	12	5.8	30

Table 2 presents a comparison of the differences between posttest and pretest scores, serving as a quantitative indicator of students' learning gains following instructional intervention. This score difference reflects the extent to which students' understanding improved after the learning process. In the experimental group, there was an average increase of 25 points—from an initial score of 60 to 85—following the implementation of the technology-enhanced learning model. This gain is considered significant and demonstrates the effectiveness of integrating Internet of Things (IoT) and ChatGPT technologies in facilitating students' conceptual understanding. In contrast, the control group experienced only a 12-point improvement, from 62 to 74, suggesting that while conventional instruction still yielded positive outcomes, its impact was not as substantial as the technology-based approach.

From the perspective of data distribution, the standard deviation in the experimental group was 6.2, slightly higher than that of the control group, which was 5.8. This indicates a degree of variability in learning gains within the experimental group, likely influenced by differences in students' adaptability to technology and individual learning styles. Nevertheless, both standard deviation values fall within a moderate range,

suggesting that the variability did not significantly disrupt the consistency of the learning outcomes. This also implies that the majority of students in the experimental group benefited consistently from the technology-integrated learning approach.

Furthermore, technology-based learning provided an interactive, contextual, and data-driven learning experience, well-aligned with the cognitive developmental characteristics of elementary students, who are typically in the concrete operational stage. The use of IoT sensors enabled students to observe real-time environmental data, such as light intensity and water pH, while ChatGPT served as a digital partner that offered narrative feedback and answered student inquiries interactively. The combined application of these technologies supported the creation of an active, constructive, and learner-responsive environment.

Considering that both groups had an equal number of participants (N = 30), the findings in Table 2 can be regarded as statistically representative and valid. The substantial increase in learning outcomes, coupled with controlled score variability, provides empirical evidence that the IoT and ChatGPT-based learning approach has a meaningful and measurable impact on improving science achievement at the elementary education level.

**Table 3.** Results of Independent Samples t-Test for Pretest and Posttest

Test Type	t-value	Degrees of Freedom (df)	p-value	Interpretation
Pretest	0.45	58	0.657	Not significant, groups are homogeneous
Posttest	6.12	58	0.000	Significant, strong difference in learning outcomes

Table 3 presents the results of statistical analysis using an independent samples t-test, aimed at evaluating whether there was a statistically significant difference in mean pretest and posttest scores between the two treatment groups. The first test was conducted on the pretest scores to ensure the equivalence of the experimental and control groups prior to the learning intervention. The results yielded a t-value of 0.45 with a p-value of 0.657, exceeding the 0.05 significance threshold. This finding indicates no statistically significant difference between the two groups before instruction, thereby supporting a more valid interpretation of the impact of the subsequent intervention.

In contrast, the posttest analysis yielded a t-value of 6.12 and a p-value of 0.000, which is far below the standard significance level. This result suggests a highly significant difference in learning outcomes between the experimental group, which received technology-integrated instruction (IoT and ChatGPT), and the control group, which was taught using conventional methods. These findings reinforce the argument that the learning gains observed in the experimental group were not due to chance, but were the direct result of the applied intervention. This is consistent with recent studies confirming that the integration of artificial intelligence and sensor technologies in instructional settings can significantly enhance learning outcomes, student engagement, and overall pedagogical effectiveness (Deng et al., 2024; Jalon Jr et al., 2024; Restrepo-Rodas et al., 2025; Setiawan et al., 2024).

The degrees of freedom (df) recorded at 58—derived from the total number of subjects in each group ( $N = 30$ )—support the validity of the analysis, as the sample size is considered sufficiently representative to draw inferential conclusions. This value further reinforces the generalizability of the findings, demonstrating that the technology-based approach is significantly more effective in improving students' cognitive achievement. In the context of elementary education, IoT enables students to make direct environmental observations, while ChatGPT serves as an interactive facilitator providing real-time, contextually relevant feedback (Ab Hamid et al., 2023; Kim, 2023; Seo et al., 2025).

Considering the overall results, it can be concluded that the instructional approach combining data-driven technology and artificial intelligence not only yields improved test scores but also produces statistically reliable and significant outcomes. This provides

compelling evidence that educational transformation through technological innovation holds substantial potential to enhance the quality of learning holistically (Almethen, 2024; Xiaoyu et al., 2025).

#### Discussion

The results of this study demonstrate that a learning approach integrating Internet of Things (IoT) and ChatGPT technologies significantly enhances students' understanding of scientific concepts, particularly those related to photosynthesis and water quality. The significant improvement in the experimental group's posttest scores compared to the control group—further confirmed by the independent t-test result with  $p < 0.05$ —provides empirical evidence that the technology-based instructional intervention is effective in improving learning outcomes. These findings are consistent with the argument made by Deng et al. (2024), who stated that the integration of artificial intelligence technologies such as ChatGPT enhances student learning outcomes through personalized content delivery and increased cognitive engagement.

Furthermore, this approach is supported by the theoretical framework of constructivism, which posits that learners build knowledge through active interaction with their environment as well as through social and technological support. Piaget emphasized the importance of concrete experiences during the concrete operational stage of development, while Vygotsky highlighted the role of social interaction and scaffolding in expanding the zone of proximal development (ZPD). In this context, the use of IoT sensors enables students to directly observe real-world phenomena—such as light intensity and water acidity levels—that are relevant to the process of photosynthesis. These activities position students as active participants in learning rather than passive recipients of information. This is reinforced by the findings of Lee & Zhai (2024), who reported that environment-based and real-time data-driven learning is highly effective in facilitating the formation of complex scientific concepts.

Meanwhile, ChatGPT functions as a digital learning partner that provides adaptive cognitive support. In a study by Han (2024), the use of ChatGPT in science learning contexts was shown to accelerate concept acquisition and support independent learning, as it offers instant, context-based responses to student queries. Kotsis (2024) further noted that ChatGPT not only helps students grasp content but also encourages

critical thinking, information evaluation, and reflective knowledge construction.

This approach has also been shown to enhance students' learning motivation. According to Simms (2024), integrating AI technologies such as ChatGPT into the classroom significantly increases student interest, curiosity, and active participation, as the interaction becomes more dialogic and personalized compared to traditional lecture-based instruction. Phorah et al. (2024) even found that applying AI in environmental topics such as water quality contributes to improved data literacy and a better understanding of global context among learners.

Moreover, the effectiveness of this method is also reflected in the development of higher-order thinking skills. That ChatGPT holds great potential in supporting the advancement of critical, reflective, and analytical thinking—core components of meaningful science learning. These findings are further reinforced by Pannu & Boosalis (2023), who demonstrated the effectiveness of ChatGPT in teaching introductory statistics through a question-driven and iterative discussion approach.

Furthermore, the integration of ChatGPT as a digital learning companion has contributed significantly to the effectiveness of science education at the elementary level. ChatGPT not only functions as a source of information but also as an interactive discussion partner capable of answering students' questions instantly, explaining complex scientific terms in simplified language, and providing personalized and contextual feedback. This supports a learning model oriented toward individual student needs—commonly known as differentiated learning. In their study, Kotsis (2024), stated that the use of ChatGPT enables learning environments to be tailored to the pace and learning styles of each student, which is crucial in accommodating diverse abilities in the classroom.

The availability of instant information through ChatGPT is particularly important for elementary students, who often face difficulties in grasping scientific concepts due to limited language skills and learning experiences. With ChatGPT's support, students are able to clarify their confusion without having to wait for the teacher to finish addressing the entire class. This is consistent with the views of Moon & Kim (2023), who highlighted that ChatGPT can bridge gaps in students' understanding of instructional content and support more independent learning processes.

In addition to serving as a facilitator for content comprehension, the use of ChatGPT has also been proven to foster learner autonomy and curiosity. By allowing students to explore data and pose questions directly to the chatbot when encountering difficulties, ChatGPT supports an active and reflective learning

process. This aligns strongly with 21st-century competencies, in which critical thinking, inquiry, and problem-solving are considered essential indicators. Villan & Santos (2023) asserted that the implementation of ChatGPT in project-based learning has demonstrably enhanced students' initiative and problem-solving abilities.

In the context of science education, this active engagement also reinforces scientific thinking from an early age. When students are accustomed to observing phenomena, formulating questions, and evaluating information, they begin to develop deeper conceptual understanding. That integrating ChatGPT into inquiry-based learning significantly strengthens students' scientific reasoning skills.

On the other hand, the use of IoT devices in environmental data collection adds a practical dimension to learning. Alshahrani & Qureshi (2024) noted that the application of environmental sensors in classrooms allows students to acquire direct empirical data, which can then be analyzed and interpreted with the help of AI tools like ChatGPT. This combination of direct observation and digital reflection creates a synergistic and meaningful learning ecosystem.

Research by Jayaweera (2023); Listyaningrum et al. (2024) further supports this claim, stating that the use of ChatGPT in elementary learning not only improves science literacy but also facilitates scientific communication for students with limited verbal abilities. In other words, this technology helps bridge the gap between students and complex scientific content.

## Conclusion

Based on the research findings and discussion presented, it can be concluded that the implementation of a learning model integrating Internet of Things (IoT) and ChatGPT-based artificial intelligence technologies has a significantly positive impact on improving the learning outcomes of elementary school students in science subjects, particularly on the topics of photosynthesis and water quality. The effectiveness of this approach is evident from the posttest average scores of the experimental group, which consistently exceeded those of the control group. The posttest improvement rate in the experimental group reached 41.7%, far surpassing the 19.3% increase observed in the control group. Additionally, the results of the independent samples t-test showed a statistically significant difference between the two groups ( $p < 0.05$ ), indicating that the observed improvement was not coincidental, but a direct result of the applied instructional intervention. The use of IoT technology in the classroom provided students with opportunities to engage in real-

world, data-driven learning experiences. By monitoring environmental variables such as light intensity, temperature, and water pH, students gained a more concrete understanding of scientific concepts that are often abstract in nature. At the same time, ChatGPT functioned as a digital facilitator, delivering personalized and responsive learning support. With its ability to explain scientific terminology in simple language and respond interactively to student inquiries, ChatGPT enhanced conceptual understanding and encouraged active student participation. This integrated approach reflects the core principles of modern pedagogy—learning that is contextual, student-centered, and technology-driven. Interaction with real-time data, coupled with AI-powered chatbot guidance, created a more meaningful learning experience, promoted deeper cognitive engagement, and strengthened students' critical thinking abilities. Moreover, the approach supports the development of 21st-century skills, including digital literacy, collaboration, scientific communication, and lifelong independent learning—skills that are increasingly relevant in addressing future global challenges. In conclusion, the findings of this study offer important implications: when thoughtfully designed and pedagogically implemented, digital technologies can serve as transformative tools in elementary science education. The integration of IoT and ChatGPT goes beyond simply supporting content delivery; it has been shown to substantially enrich the learning process—both cognitively and in terms of essential skill development. Therefore, this study urges educators and policymakers to consider technology integration as a central strategy for improving learning quality in the digital era.

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This article was written by four authors, namely A, I.A.N., A, and M.A.S. All authors carried out each stage of the research together.

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#### Conflicts of Interest

The authors declare no conflict of interest.

#### References

- Ab Hamid, E. A. H., Maskur, H., & Mutalib, R. A. (2023). The use of ChatGPT applications in learning: Impact on understanding and student engagement in TVET institutions. *Malaysian Journal of Information and Communication Technology (MyJICT)*, 78–87. <https://doi.org/10.53840/myjict8-2-98>
- Al Shloul, T., Mazhar, T., Abbas, Q., Iqbal, M., Ghadi, Y. Y., Shahzad, T., Mallek, F., & Hamam, H. (2024). Role of activity-based learning and ChatGPT on students' performance in education. *Computers and Education: Artificial Intelligence*, 6, 100219. <https://doi.org/10.1016/j.caeai.2024.100219>
- Alfiani, R., & Sulisworo, D. (2023). Leveraging ChatGPT for developing learning object material: a multi-representation approach to teaching water pollution. *Formatif: Jurnal Ilmiah Pendidikan MIPA*, 13(2). <https://doi.org/10.30998/formatif.v13i2.19472>
- Aliya, N., Suriani, A. B., Wong, K. T., Azzam, A. B., & Adli, M. (2024). Integrasi Aplikasi berasaskan Kecerdasan Buatan dalam Pembelajaran Digital dan Kaedah Pengajaran dan Pembelajaran Fizik Kuantum: Tinjauan Literatur. *Jurnal Pendidikan Sains Dan Matematik Malaysia*, 14(2), 155–170. Retrieved from <https://ejournal.upsi.edu.my/index.php/JPSMM/article/download/10541/5386>
- Almethen, A. (2024). Challenges in implementing—artificial intelligence applications in secondary-level education: A teacher-centric perspective. *Journal of Faculty of Education-Assiut University*, 40(5.2), 1–32. <https://doi.org/10.21608/mfes.2024.363254>
- Alshahrani, K., & Qureshi, R. J. (2024). Review the prospects and obstacles of AI-enhanced learning environments: the role of ChatGPT in education. *International Journal of Modern Education and Computer Science*, 16(4), 71–86. <https://doi.org/10.5815/ijmecs.2024.04.06>
- Becker, J. K., & Starobinski, D. (2022). Optimizing freshness in IoT scans. *2022 IEEE 8th World Forum on Internet of Things (WF-IoT)*, 1–6. <https://doi.org/10.1109/WF-IoT54382.2022.10152289>
- Binder, M., & Mezhuyev, V. (2024). A framework for creating an IoT system specification with ChatGPT. *Internet of Things*, 27, 101218. <https://doi.org/10.1016/j.iot.2024.101218>
- Branch, R. M. (2009). *Instructional Design-The ADDIE*

- Approach* (1st ed.). Springer US. <https://doi.org/10.1007/978-0-387-09506-6>
- Chen, T. C., Kaminski, E., Koduri, L., Singer, A., Singer, J., Couldwell, M., Delashaw, J., Dumont, A., & Wang, A. (2023). Chat GPT as a neuro-score calculator: analysis of a large language model's performance on various neurological exam grading scales. *World Neurosurgery*, 179, e342--e347. <https://doi.org/10.1016/j.wneu.2023.08.088>
- Deng, W. H., Yurrita, M., Díaz, M., Suh, J., Judd, N., Groves, L., Shen, H., Eslami, M., & Holstein, K. (2024). Responsible Crowdsourcing for Responsible Generative AI: Engaging Crowds in AI Auditing and Evaluation. *Proceedings of the AAAI Conference on Human Computation and Crowdsourcing*, 12, 148-150. <https://doi.org/10.1609/hcomp.v12i1.31609>
- Echiverri, L. L., Song, S., Wang, T., Liang, S., & others. (2025). ChatGPT as a Mediating Tool in Education: Enhancing Learning Efficiency, Academic Performance, and Academic Self-Concept in Effort-Talent Focused Environments. *Conference Proceedings. The Future of Education 2025*. Retrieved from [https://conference.pixel-online.net/library\\_scheda.php?id\\_abs=7385&id\\_cr=2&id\\_edition=49&type=conference](https://conference.pixel-online.net/library_scheda.php?id_abs=7385&id_cr=2&id_edition=49&type=conference)
- Egbemhenge, A. U., Ojeyemi, T., Iwuzor, K. O., Emenike, E. C., Ogunsanya, T. I., Anidiobi, S. U., & Adeniyi, A. G. (2023). Revolutionizing water treatment, conservation, and management: Harnessing the power of AI-driven ChatGPT solutions. *Environmental Challenges*, 13, 100782. <https://doi.org/10.1016/j.envc.2023.100782>
- Fadillah, M. A., Usmeldi, U., Lufri, L., Mawardi, M., & Festiyed, F. (2024). Exploring user perceptions: The impact of ChatGPT on high school students' physics understanding and learning. *Advances in Mobile Learning Educational Research*, 4(2), 1197-1207. <https://doi.org/10.25082/AMLER.2024.02.013>
- Farhana, N., & Arini, N. W. (2023). Chatbot Rain for Grade 5 in Water Cycle Material of Science Subject. *Jurnal Penelitian Pendidikan IPA*, 9(9), 7170-7178. <https://doi.org/10.29303/jppipa.v9i9.4521>
- Guler, S. D., Sotelo, S., & Iwabuchi, M. (2022). Tekniverse: Towards a connected future for sensors, education, and action: Fostering Environmental Literacy with IoT and Physical Computing. *Proceedings of the 21st Annual ACM Interaction Design and Children Conference*, 583-589. <https://doi.org/10.1145/3501712.3535291>
- Han, Z. (2024). Chatgpt in and for second language acquisition: A call for systematic research. *Studies in Second Language Acquisition*, 46(2), 301-306. <https://doi.org/10.1017/S0272263124000111>
- Istikomah, E., Suryadi, D., Prabawanto, S., & Nurlaelah, E. (2024). Masa depan pembelajaran di abad 21: keterampilan berpikir kreatif dan matematis di tengah maraknya artificial intelligence (AI). Global-RCI. Retrieved from <https://shorturl.asia/cxmNw>
- Jalon Jr, J. B., Chua, G. A., & de Luna Torres, M. (2024). ChatGPT as a Learning Assistant: Its Impact on Students Learning and Experiences. *International Journal of Education in Mathematics, Science and Technology*, 12(6), 1603-1619. Retrieved from <https://eric.ed.gov/?id=EJ1465724>
- Jayaweera, M. (2023). From Jargon to Clarity: Enhancing Science Communication with ChatGPT. *Vidyodaya Journal of Science*, 26(01). <https://doi.org/10.31357/vjs.v26i01.6405>
- Kim, W. (2023). Analysis of the educational effects regarding the use of ChatGPT in compulsory basic coding subjects. *Korean Journal of General Education*, 17(5), 113-123. <https://doi.org/10.46392/kjge.2023.17.5.113>
- Kotsis, K. T. (2024a). ChatGPT as teacher assistant for physics teaching. *EIKI Journal of Effective Teaching Methods*, 2(4). <https://doi.org/10.59652/jetm.v2i4.283>
- Kotsis, K. T. (2024b). Integrating ChatGPT into the inquiry-based science curriculum for primary education. *European Journal of Education and Pedagogy*, 5(6), 28-34. <https://doi.org/10.24018/ejedu.2024.5.6.891>
- Lee, G.-G., & Zhai, X. (2024). Using ChatGPT for science learning: A study on pre-service teachers' lesson planning. *IEEE Transactions on Learning Technologies*, 17, 1643-1660. <https://doi.org/10.1109/TLT.2024.3401457>
- Listyaningrum, P., Retnawati, H., Harun, H., & Ibda, H. (2024). Digital learning using ChatGPT in elementary school mathematics learning: a systematic literature review. *Indonesian Journal of Electrical Engineering and Computer Science*, 36(3), 1701. <https://doi.org/10.11591/ijeecs.v36.i3.pp1701-1710>
- Moon, J., & Kim, S. B. (2023). Analyzing elementary teachers' perception of ChatGPT. *2023 5th International Workshop on Artificial Intelligence and Education (WAIE)*, 43-47. <https://doi.org/10.1109/WAIE60568.2023.00015>
- Munsarif, M., Sam'an, M., & Raharjo, S. (2024). Pelatihan ChatGBT kepada Guru di Majelis Pendidikan Muhammadiyah kota semarang untuk Peningkatan literasi digital. *Jurnal Surya Masyarakat*, 6(2), 269-275. <https://doi.org/10.26714/jsm.6.2.2024.269-275>
- Namilae, A., & Leddo, J. (2024). Comparing the

- Effectiveness of Chat GPT and Teacher-generated Content for Teaching Students. *International Journal of Social Science and Economic Research*, 9(7), 2554–2564.  
<https://doi.org/10.46609/IJSSER.2024.v09i07.031>
- Ngo, T. T. A. (2023). The perception by university students of the use of ChatGPT in education. *International Journal of Emerging Technologies in Learning (Online)*, 18(17), 4.  
<https://doi.org/10.3991/ijet.v18i17.39019>
- Pannu, J., & Boosalis, C. (2023). A Use-Case for Implementing ChatGPT to Augment Teaching an Introductory Statistics Course. *Proceedings of the Future Technologies Conference*, 196–203.  
[https://doi.org/10.1007/978-3-031-47454-5\\_15](https://doi.org/10.1007/978-3-031-47454-5_15)
- Phorah, K., Sibiya, M., & Sumbwanyambe, M. (2024). Prompt Design through ChatGPT's Zero-Shot Learning Prompts: A Case of Cost-Sensitive Learning on a Water Potability Dataset. *Informatics*, 11(2), 27.  
<https://doi.org/10.3390/informatics11020027>
- Restrepo-Rodas, G., Barajas-Gamboa, J. S., Ortiz Aparicio, F. M., Pantoja, J. P., Abril, C., Al-Baqain, S., Rodriguez, J., & Guerron, A. D. (2025). The Role of AI in Modern Hernia Surgery: A Review and Practical Insights. *Surgical Innovation*, 32(3), 301–311. <https://doi.org/10.1177/15533506251328481>
- Rukhiran, M., Phaokla, N., & Netinant, P. (2022). Adoption of environmental information chatbot services based on the internet of educational things in smart schools: Structural equation modeling approach. *Sustainability*, 14(23), 15621.  
<https://doi.org/10.3390/su142315621>
- Sanabria Zepeda, J. C., Olivo Montaña, P. G., Mercado Rojas, J. G., Antelis Ortiz, J. M., & Limón Garcia, A. (2024). *Integrating IoT and civic education: SKILIKET system as an approach to environmental monitoring and awareness*. Tecnológico de Monterrey.
- Seo, M., Cho, E., Oh, H., Kim, S., & Maeng, H. (2025). A Study on Pre-service Teachers' Perception and Utilization Competencies of AI and Digital Tools in Science and Mathematics. *Journal of The Korean Association For Science Education*, 45(3), 223–240.  
<https://doi.org/10.14697/jkase.2025.45.3.223>
- Setiawan, Y. D., Yudha, L. G. O. P., Mulyono, Y. A., Simalango, V. M. A., & Karnalim, O. (2024). Chat GPT Impact Analysis on API Testing: A Controlled Experiment. *Journal of Applied Informatics and Computing*, 8(2), 350–357.  
<https://doi.org/10.30871/jaic.v8i2.8182>
- Simms, R. C. (2024). Work with ChatGPT, not against: 3 teaching strategies that harness the power of artificial intelligence. *Nurse Educator*, 49(3), 158–161.  
<https://doi.org/10.1097/NNE.0000000000001634>
- Tabuenca, B., Moreno-Sancho, J.-L., Arquero-Gallego, J., Greller, W., & Hernández-Leo, D. (2023). Generating an environmental awareness system for learning using IoT technology. *Internet of Things*, 22, 100756.  
<https://doi.org/10.1016/j.iot.2023.100756>
- Terzieva, V., Ilchev, S., & Todorova, K. (2022). The role of Internet of Things in smart education. *IFAC-PapersOnLine*, 55(11), 108–113.  
<https://doi.org/10.1016/j.ifacol.2022.08.057>
- Trung, H. D., Dung, N. X., & Trung, N. H. (2020). Building IoT analytics and machine learning with open source software for prediction of environmental data. *International Conference on Hybrid Intelligent Systems*, 134–143.  
[https://doi.org/10.1007/978-3-030-73050-5\\_14](https://doi.org/10.1007/978-3-030-73050-5_14)
- Utami, A. S., Kaniawati, I., & Sriyati, S. (2023). Citizen Science: Fostering Creative Thinking in Environmental Education. *International Conference on Intellectuals' Global Responsibility (ICIGR 2022)*, 255–260. <https://doi.org/10.1088/1742-6596/1760/1/012027>
- Villan, F., & Santos, R. P. dos. (2023). ChatGPT as co-advisor in scientific initiation: Action research with project-based learning in elementary education. *Computers and Society*.  
<https://doi.org/10.17648/acta.scientiae.7474>
- Wibowo, A. M., Utaya, S., Wahjoedi, W., Zubaidah, S., Amin, S., & Prasad, R. R. (2024). Critical thinking and collaboration skills on environmental awareness in project-based science learning. *Jurnal Pendidikan IPA Indonesia*, 13(1), 103–115.  
<https://doi.org/10.15294/jpii.v13i1.48561>
- Xiaoyu, W., Zainuddin, Z., Leng, C. H., Wenting, D., & Li, X. (2025). Evaluating the efficacy of ChatGPT in environmental education: findings from heuristic and usability assessments. *On the Horizon: The International Journal of Learning Futures, ahead-of-print*. <https://doi.org/10.1108/OTH-11-2024-0079>
- Yamin, Y., Permanasari, A., Redjeki, S., & Sopandi, W. (2020). Project based learning to enhance creative thinking skills of the non-science students. *Jhss (Journal of Humanities and Social Studies)*, 4(2), 107–111. <https://doi.org/10.33751/JHSS.V4I2.2450>