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The Integration Internet of Things (IoT) In Science Education to Improve Learning Quality: A Systematic Literature Review

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Abstract: The advancement of digital technology, particularly the Internet of Things (IoT), has provided significant opportunities to enhance the quality of science education in the 21st century. However, the implementation of IoT in educational settings remains suboptimal and fragmented, with existing research findings still dispersed across various studies. Therefore, this study aims to analyze and synthesize research findings related to the integration of IoT in science learning and its impact on educational quality. This study employs a Systematic Literature Review (SLR) method. Data were collected through a systematic search of articles in major academic databases, including Google Scholar, Scopus, Web of Science, and Garuda, covering publications from 2016 to 2025. Based on the selection process using the PRISMA framework, a total of 30 articles met the inclusion criteria and were included in the analysis. The findings indicate that the integration of IoT in science education has shown a significant increase in recent years and is commonly implemented through the use of microcontroller-based sensors integrated with instructional models such as Project-Based Learning (PjBL), STEM, and inquiry-based learning. Furthermore, the results reveal that IoT implementation has a positive impact on the quality of learning, as evidenced by improvements in students' learning outcomes, engagement, and motivation. In addition, IoT contributes to the enhancement of scientific literacy and critical thinking skills through data-driven and experiential learning approaches. Despite these promising outcomes, the implementation of IoT still faces several challenges, including limitations in infrastructure, cost, and teachers' competencies. Therefore, support from multiple stakeholders is required to optimize the utilization of IoT in science education. This study is expected to serve as a reference for the development of technology-based learning to improve the quality of science education.

Keywords: Internet of Things; Science learning; Learning quality; Scientific literacy; Critical thinking.

Introduction

The rapid advancement of science and technology in the 21st century has brought significant changes across various aspects of life, including the field of education. Digital transformation requires learning systems that are not only oriented toward content mastery but also toward the development of 21st-century skills, such as critical thinking, problem-solving, creativity, and technological literacy. In this context, science education plays a strategic role, as it not only functions to transfer knowledge but also to foster scientific thinking skills and a deeper understanding of natural phenomena. Therefore, the quality of science learning becomes a crucial factor in determining students' readiness to face global challenges. However, the quality of science education in Indonesia still faces several challenges. Results from international assessments, such as the Programme for International Student Assessment (PISA) conducted by the OECD, indicate that Indonesian students' scientific performance remains below the average of OECD member countries (OECD, 2019). This suggests that current science learning practices have not yet fully succeeded in developing students' conceptual understanding and higher-order thinking skills. One contributing factor is the continued dominance of teacher-centered instructional approaches, along with the limited integration of technology in the learning process.

Along with the advancement of digital technology, various innovations have emerged that can be utilized to enhance the quality of learning, one of which is the

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Internet of Things (IoT). IoT refers to a concept that enables physical devices to be interconnected through internet networks in order to collect and exchange data in real time. According to Luigi Atzori et al. (2010), IoT facilitates the integration of the physical and digital worlds through sensors and smart devices capable of generating continuous, real-time data. In the context of education, this technology has the potential to create more interactive, contextual, and data-driven learning environments.

The integration of the Internet of Things (IoT) into science education offers significant opportunities to enhance the quality of learning. Using IoT-based sensors and devices, students can conduct experiments directly, collect real-time data, and analyze scientific phenomena in a more in-depth manner. This approach makes learning more meaningful, as students are not merely passive recipients of information but actively engaged in the process of knowledge construction. Furthermore, IoT-based learning supports the implementation of instructional approaches such as STEM, Project-Based Learning (PjBL), and inquiry-based learning, which have been widely recognized as effective in improving the quality of science education.

Several studies have demonstrated that the use of the Internet of Things (IoT) in education can enhance student engagement, learning motivation, and overall learning outcomes. A study by Benita et al. (2021) found that IoT-based learning environments can improve students' analytical and problem-solving skills through a data-driven learning approach. In addition, research by Mohammed Al-Emran et al. (2020) highlights that IoT plays a crucial role in creating smart learning environments that support more flexible and adaptive learning processes tailored to students' needs. The quality of learning is not solely measured by cognitive outcomes but also by the learning process itself, which involves active interaction, appropriate use of technology, and students' ability to apply knowledge in real-life contexts. In this regard, the integration of IoT makes a significant contribution by providing authentic and contextual learning experiences. Through the availability of real-time data, students can develop deeper skills in observation, analysis, and evaluation, thereby optimizing the overall quality of learning.

Despite its significant potential, the implementation of the Internet of Things (IoT) in science education still faces several challenges, including limited infrastructure, insufficient teacher competencies in utilizing technology, and restricted access to IoT devices in schools. Furthermore, comprehensive research examining the integration of IoT in science learning particularly in relation to improving learning quality remains limited and fragmented across various studies employing diverse approaches.

Based on these issues, a systematic study is needed to analyze and synthesize research findings related to the integration of the Internet of Things (IoT) in science education. Therefore, this study employs a Systematic Literature Review (SLR) approach to comprehensively examine how the integration of IoT in science learning can improve the quality of education. The findings of this study are expected to contribute to the development of technology-based learning innovations and serve as a reference for educators and researchers in enhancing the quality of science education in the future.

Method

This study employs a Systematic Literature Review (SLR) approach aimed at identifying, evaluating, and synthesizing findings from previous studies in a systematic and transparent manner. The SLR method was selected because it provides a comprehensive overview of the integration of the Internet of Things (IoT) in science education and its impact on students' scientific literacy and critical thinking skills. This approach follows the stages proposed by Barbara Kitchenham (2004), which include the planning, conducting, and reporting phases of the review process.

In the planning stage, the researchers formulated the scope of the study and developed research questions that include: (1) how research trends related to the implementation of IoT in science education have evolved; (2) what the characteristics of IoT implementation in science learning are; (3) how the implementation of IoT influences students' scientific literacy; (4) how the implementation of IoT affects students' critical thinking skills; and (5) what the advantages and challenges are in applying IoT in science education. Furthermore, relevant search keywords were determined, including "Internet of Things in science education," "IoT AND scientific literacy," "IoT AND critical thinking," and "IoT in science learning."

In the conducting stage, the literature search was carried out through various scientific databases, including Google Scholar, Scopus, Web of Science, and Garuda. The retrieved articles were then screened using predefined inclusion and exclusion criteria. The inclusion criteria comprised studies that addressed the implementation of IoT in science education, were related to scientific literacy and/or critical thinking skills, were published in peer-reviewed journals or conference proceedings and fell within the publication range of 2016–2025. Meanwhile, the exclusion criteria included articles that were not relevant to the field of education, were not available in full-text form, or were duplicates. The article selection process was conducted systematically using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)

framework, involving the stages of identification, screening, eligibility, and inclusion, resulting in a set of studies deemed appropriate for further analysis.

The selected data were subsequently analyzed using descriptive qualitative analysis techniques. The analysis process was conducted by categorizing the articles based on publication year, research type, and the characteristics of IoT implementation in learning. In addition, the researchers identified key findings related to the enhancement of students' scientific literacy and critical thinking skills. The results of the analysis were then synthesized to generate comprehensive conclusions regarding the effectiveness and contribution of IoT in science education.

Data collection in this study was conducted using the documentation method, by gathering and reviewing relevant scientific articles. To ensure the validity and reliability of the data, the researchers selected articles based on clearly defined criteria, utilized credible academic databases, and applied source triangulation by combining both national and international journal publications. Therefore, the SLR method employed in this study is expected to provide a comprehensive and systematic understanding of the integration of IoT in science education and its impact on students' scientific literacy and critical thinking skills.

Result and Discussion

Tabel 1. Articles discussing the integration of the Internet of Things (IoT) in science education.

Authors	Year	Title	Result
Harianto et al.	2025	*Internet of things (IOT)* untuk pembelajaran sains kontekstual pada calon guru sains	The use of the Internet of Things (IoT) strengthens the understanding of scientific concepts, enhances the engagement of pre-service science teachers, and supports the development of critical thinking skills.
Riansyah et al.	2025	Penerapan Teknologi IoT pada Hidroponik di Sekolah Dasar untuk Meningkatkan Literasi Sains dan Kesadaran Lingkungan	It has significant potential to enhance students' understanding of science and technology, as well as to foster early awareness of sustainable agricultural practices.
Sukmawati et al.	2025	*Integrating Web-Based IoT Learning Media to Enhance Critical Thinking and Problem-Solving Skills in Vocational Education*	There was a statistically significant improvement in students' critical thinking and problem-solving skills in the experimental group compared to the control group.
Puspita et al.	2024	Pengembangan Alat Pendeteksi Banjir Berbasis *Internet of Things (IoT)* sebagai Media Pembelajaran Fisika untuk Siswa SMA	The developed Internet of Things (IoT)-based flood detection device is considered feasible for use as a physics learning medium.
Budianti et al.	2025	Pemanfaatan Teknologi *Internet of Things* untuk Penunjang Model Pembelajaran Science, Technology, Engineering and Mathematics	Learning activities involving the application of IoT within a STEM framework significantly support the understanding of fundamental concepts and theories, as well as their relevance to modern technology, particularly in the fields of Physics and Biology related to temperature and liquid pH measurement.
Damayanti et al.	2025	Pengembangan Media Pembelajaran Fisika Berbasis IoT Pada Sistem Keamanan Rumah Adat Palu	The integration of IoT technology with local wisdom, manifested in the form of a traditional house miniature, can enhance the relevance of physics learning, increase student motivation, and foster awareness of cultural preservation.
Nurtamam et al.	2025	Efektivitas Pembelajaran Flipped Learning Berbasis *Internet of Things (IoT)* Untuk Meningkatkan Kemampuan Pemecahan Masalah Siswa: Meta-analysis	The IoT-based flipped learning model can improve students' problem-solving skills, foster greater creativity and innovation in learning, and enable students to access learning information more quickly and easily through the internet.
Itqan et al.	2023	Pengembangan Media Pembelajaran Matematika Berbasis IoT dengan Pendekatan *Problem Based Learning*	To develop an interactive learning medium that can enhance students' learning abilities. The developed media is also compatible with smartphones operating on the Android-based operating system.

Authors	Year	Title	Result
Larashati et al.	2023	*Project-Based Learning Based on the Internet of Things to Improve Students' Science Process Skills*	The Internet of Things (IoT)-based Project-Based Learning (PjBL) model has been proven to improve students' science process skills (SPS), and the results of the t-test indicate a statistically significant effect.
Arin et al.	2024	Pengembangan Perangkat Pembelajaran Sistem Kendali On/Off Menggunakan Mikrokontroler Berbasis Iot (Internet of Things) Pada Elemen Sistem Kendali Elektronik	The IoT (Internet of Things)-based on/off control system learning device using a microcontroller that has been developed is deemed feasible for implementation as a learning tool in the Electronic Control Systems element for Grade XI Industrial Electronics Engineering at SMK Negeri 1 Jabon.
Darniati et al.	2022	Perancangan Alat Ukur Induksi Magnet Pada Solenoida Berbasis Internet of Things	An Internet of Things (IoT)-based magnetic induction measuring instrument for a solenoid is considered feasible and can be effectively utilized in the learning process.
Wijaya et al.	2023	Rancangan *Project Based E-Learning* Berbasis *Internet of Thinks* untuk Meningkatkan Kemampuan Berpikir Kreatuf Mahasiswa	The results of the study indicate that the use of an IoT-based project-based e-learning design can enhance students' creative thinking skills through more interactive, collaborative, and contextual learning. Furthermore, the integration of IoT technology facilitates student-centered learning activities and provides a more personalized and engaging learning experience.
Tamaji et al.	2025	Inovasi Modul Embedded-IoT Sebagai Media Pembelajaran Stem Di Smk: Studi Kasus Di Smk Siang Dan Smk Kawung 1 Surabaya	Enhances the technical skills of students and teachers in the field of the Internet of Things (IoT), introduces up-to-date technologies into the curriculum, and strengthens project-based learning competencies that are relevant to industry needs.
Nainggolan et al.	2025	Impementasi IoT dan Sensor Multifungsi dalam praktikum induksi elektromagnetik	The results of the study indicate a significant improvement in conceptual understanding scores, increasing from 59.8% to 81.6% ($p < 0.001$), with 84.7% of students achieving good to very good levels of understanding. In addition, questionnaire data revealed high levels of satisfaction and motivation, particularly in terms of interactivity, speed of data analysis, and ease of visualizing physical phenomena. The implementation of IoT and multifunctional sensors has been proven effective in enhancing the accuracy and efficiency of observations, strengthening analytical thinking skills, and creating learning experiences that are aligned with the demands of modern technological developments.
Pratiwi et al.	2021	Smart Learning Torso Berbasis IoT: Tool Cerdas Pembelajaran Mandiri untuk Menumbuhkan Self-Effycacy Anak Berkebutuhan Khusus	The developed media resulted in cognitive achievement of 78.3%, affective outcomes of 80%, and psychomotor skills of 86.25%. Students were also able to identify the main human body organs and accurately indicate their locations.
Ridho et al.	2025	Mengembangkan Kreativitas Siswa SMK Negeri 2 Padang Melalui Pelatihan Sistem Pintar Berbasis *Internet of Things (IoT)*	Enhances students' understanding of microcontrollers, sensor and actuator programming, as well as the implementation of IoT systems using platforms such as Blynk and Telegram.
Hamid et al.	2022	*Development of Internet of Things Based Learning Media Through STEM Investigative Science Learning Environment Approach to Improve Student Learning Outcomes*	The results of the study indicate that the developed instructional media is feasible for implementation in the learning process. In addition, it demonstrates an improvement in students' learning mastery.
Atmojo et al.	2024	*The Effectiveness of An Internet of Things (IoT)-based Virtual Science Laboratory on Nervous System Material in Science Course*	The results of the study indicate that the Internet of Things (IoT)-based virtual science laboratory on the nervous system topic is effective in improving students' conceptual understanding. Furthermore, the results of the t-test reveal a statistically significant difference between the control group and the experimental group in terms of the

Authors	Year	Title	Result
			effectiveness of using the IoT-based virtual science laboratory on the nervous system material.
Benardi et al.	2025	Pendidikan kebencanaan game edukasi Internet of Things (IoT) untuk menguatkan kesiapsiagaan siswa terhadap gempa bumi tsunami megathrust	The results of the study indicate that, after the implementation of an Internet of Things (IoT)-based educational game, students' disaster knowledge showed a significant improvement. In addition, there was a statistically significant difference between the pre-test and post-test results, indicating that students had positive perceptions of and strong engagement with the learning media.
Nasution et al.	2025	*Development of IoT-Based Physics Teaching Aids for Basic Physics Practicum*	The findings of the study indicate that Internet of Things (IoT)-based instructional media can improve the accuracy of experimental data, enhance interactivity, and increase students' learning motivation and conceptual understanding in basic physics topics.
Nurlia et al.	2024	*Development of an Internet of Things control solution (IoT consol) learning program in the physics learning media course*	The results of the product development study indicate that the overall feasibility level of the instructional components reached 93%, which falls into the very good category. Meanwhile, students' responses yielded a score of 77.77%, which is categorized as good.
Mastum et al.	2022	*Development of IoT-Based Physics Learning Media and Its Effect on Students' Critical Thinking Ability*	The results of the development of an Internet of Things (IoT)-based physics learning media indicate that expert evaluations placed the product in the "highly feasible" category. Questionnaire results further revealed that the media was rated as "very good," with a percentage score of 90.92%. In addition, post-test results demonstrated that the IoT-based physics learning media was effective in improving students' critical thinking skills, as indicated by an N-gain score of 0.73.
Liana et al.	2020	*The Development of Thermodynamics Law Experiment Media Based on IoT: Laboratory Activities Through Science Problem Solving for Gifted Young Scientists*	The Internet of Things (IoT)-based thermodynamics law experimental media is considered feasible for use as an instructional medium in practical activities on thermodynamics concepts.
Hendri et al.	2025	*Integration of Arduino Uno and IoT Concepts in the Development of Magnetic Field Learning Media: A Qualitative Descriptive Study*	The results of the study indicate that the use of an Arduino-based teslameter enhances student engagement and improves their conceptual understanding of magnetic field phenomena. In addition, students demonstrated high interest in technology-based learning and provided positive responses toward the development of the device.
Fitriasih et al.	2025	*Smart biotech learning media: A STEAM-IoT based to improve students' problem-solving abilities and collaboration skills*	The Internet of Things (IoT)-based Smart Biotech learning media, implemented through a STEAM approach, has been shown to significantly improve students' problem-solving and collaboration skills. Furthermore, the average levels of problem-solving ability and collaboration were higher in the class that implemented the IoT-based Smart Biotech learning media with a STEAM approach compared to the class that did not implement it.
Liana et al.	2020	*Science activity for gifted young scientist: thermodynamics law experiment media based IoT*	The Internet of Things (IoT)-based thermodynamics law experimental media is considered feasible for use as a learning medium in teaching thermodynamics concepts.
Boisandi & Mastun	2025	Implementasi Alat Ukur Kemagnetan Berbasis Microcontroller Arduino Uno Sebagai Media Pembelajaran Saintifik untuk Meningkatkan Kemampuan Literasi Sains	There was a significant improvement in students' scientific literacy following the use of the magnetic measurement instrument. In addition, student responses indicated that the developed media was engaging, easy to use, and effective in explaining magnetic concepts.
Bunyamin	2023	*Internet of Things for Project-Based Learning in "Vocational High School Building Village Program*	The results of the study indicate that students at SMK 2 Kuningan were able to identify problems within the community and propose solutions to those issues.

Authors	Year	Title	Result
			Furthermore, the Internet of Things (IoT)-based Project-Based Learning (PjBL) model has been shown to be effective in enhancing students' vocational skills.
Beng et al.	2021	*STEM Learning Model Design Using IoT for Primary School Students*	The results of the study indicate that STEM learning through an Internet of Things (IoT)-based digital plant growth sensor has the potential to enhance fundamental skills in recording, describing, and analyzing data, which are essential competencies in the fields of Biology, Technology, Engineering, and Mathematics.
Benita et al.	2021	*A smart learning ecosystem design for delivering Data-driven Thinking in STEM education*	This study emphasizes the importance of implementing data-driven thinking as a core element in the learning environment, as it can promote collaborative learning experiences and foster the development of various STEM skills, including problem identification and problem-solving abilities, cognitive skills, analytical thinking, spatial abilities, mental object manipulation, organization, leadership, and management skills.

Based on the analysis of 30 articles selected through a Systematic Literature Review (SLR) approach using the PRISMA framework, a comprehensive overview of the integration of the Internet of Things (IoT) in science education was obtained. In general, research on IoT in science learning shows a significant upward trend over the period from 2016 to 2025. This increase indicates that IoT is increasingly being adopted as an innovation in education, particularly at the secondary and higher education levels. This finding is consistent with the study by Benita et al. (2021), which reported that the implementation of IoT in STEM-based learning environments has grown significantly and contributes to the development of 21st-century skills. Furthermore, research by Mohammed Al-Emran et al. (2020) highlights that IoT has become an integral part of the smart education ecosystem, enhancing learning effectiveness through the integration of digital technologies. Conceptually, this is supported by Luigi Atzori et al. (2010), who state that IoT enables real-time data exchange between physical devices and digital systems.

In terms of implementation characteristics, the findings indicate that the application of the Internet of Things (IoT) in science education commonly utilizes sensor devices such as temperature, light, and humidity sensors connected to microcontrollers like Arduino or ESP8266. The data generated from these devices are used as learning resources in scientific investigation processes. This finding is consistent with the study by Gwo-Jen Hwang et al. (2018), which demonstrates that IoT-based learning environments support experimental learning and enhance student engagement. Furthermore, research by Ching Sing Chai et al. (2019) indicates that the integration of IoT in inquiry-based learning provides students with opportunities to independently explore data. IoT integration is also frequently combined with instructional models such as Project-Based Learning (PjBL) and STEM, which, according to Askar Zhamanov et al. (2018), are effective in improving problem-solving skills and increasing student engagement in science learning.

The synthesis results also indicate that the integration of the Internet of Things (IoT) has a positive impact on the quality of science education. This is reflected in improvements in students' learning outcomes, motivation, and engagement during the learning process. A study by Skloul and Kenwright (2022) demonstrates that the use of IoT in education can create interactive and adaptive learning environments, thereby enhancing overall learning quality. In addition, research by Charith Perera et al. (2019) found that IoT-based learning increases student engagement through data-driven learning activities. This suggests that IoT supports more meaningful learning, as students are directly involved in the learning process. In relation to scientific literacy, the findings reveal that IoT integration contributes to improving students' ability to understand scientific phenomena, interpret data, and use scientific evidence in decision-making. This is supported by the study conducted by Yueh-Min Hsu et al. (2017), which shows that the use of IoT-based technology in science learning enhances data interpretation skills and conceptual understanding. Furthermore, research by Yeh-Cheng Wu et al. (2021) states that IoT-based learning improves scientific literacy through contextual and real-world learning experiences. These findings are aligned with the scientific literacy framework developed by the OECD, which emphasizes the importance of understanding and evaluating scientific evidence in everyday life.

In addition to scientific literacy, the integration of the Internet of Things (IoT) has also been shown to enhance students' critical thinking skills. This is

reflected in the improvement of students' abilities to analyze data, evaluate experimental results, and draw evidence-based conclusions. A study by Kim et al. (2021) indicates that the use of IoT-based laboratories can improve critical thinking skills through experimental data analysis activities. Furthermore, research by Estrada et al. (2020) found that IoT-integrated smart laboratory learning enhances students' evaluation and problem-solving skills. These findings are consistent with the critical thinking indicators proposed by Robert H. Ennis, which include interpretation, analysis, inference, and evaluation as key components of critical thinking.

However, despite its various advantages, the implementation of IoT in science education still faces several challenges. Some studies, such as those conducted by Al-Emran et al. (2020), indicate that limited infrastructure, high device costs, and low teacher competency are the main barriers to the adoption of IoT in educational settings. In addition, research by Ghashim & Arshad (2023) also highlights that technological readiness and internet access are critical factors in the successful implementation of IoT. Therefore, support from various stakeholders is required to address these challenges, both through the improvement of facilities and the provision of training for educators.

Overall, the results and discussion indicate that the integration of the Internet of Things (IoT) in science education has great potential to enhance the quality of learning. IoT enables a more interactive, contextual, and data-driven learning environment, thereby not only improving learning outcomes but also fostering students' scientific literacy and critical thinking skills. These findings are supported by various previous studies that consistently demonstrate the positive impact of IoT implementation in education on the development of 21st-century skills. Therefore, the integration of IoT in science learning is a relevant and strategic innovation for improving the quality of education in the digital era.

Conclusion

Based on the results of the analysis and synthesis of 30 articles using a Systematic Literature Review (SLR) approach, it can be concluded that the integration of the Internet of Things (IoT) in science education has significant potential to improve the quality of learning. Research trends indicate that the use of IoT in education has increased considerably in recent years, particularly in the context of technology-based learning and 21st-century skills development. The implementation of IoT in science learning is generally carried out through the use of sensor devices connected to microcontrollers and integrated with innovative learning models such as Project-Based Learning (PjBL), STEM, and inquiry-based learning.

The results of the study indicate that IoT integration has a positive impact on the quality of learning, as reflected in improved learning outcomes, student engagement, and motivation. In addition, IoT also contributes to enhancing scientific literacy, particularly in understanding scientific phenomena, interpreting data, and using scientific evidence in decision-making. Students' critical thinking skills also improve through activities involving data analysis, evaluation of experimental results, and problem-solving based on real-time data. However, the implementation of IoT in science education still faces various challenges, such as limited infrastructure, the cost of device procurement, and teachers' low competence in utilizing technology. Therefore, integrated efforts from various stakeholders, including government, educational institutions, and educators, are needed to support the optimal use of IoT in learning.

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