



IJIS

Journal of the Institute of Education
Obafemi Awolowo University, Ile-Ife, Nigeria

ISSN: 3043-6400

Vol. 2, No. 1, 2025

CALL FOR PAPERS
IFE JOURNAL OF INTEGRATED SCIENCE (IJIS)

NOTE TO CONTRIBUTOR

Ife Journal of Integrated Science, (IJIS) is a Bi-annual publication of Institute of Education, Obafemi Awolowo University, Ile-Ife (Integrated Science Unit). The Journal aims at improving the quality of academic and research manuscripts submitted by scholars and researchers, through peer review process, and disseminate the publications through open access to practitioners, educators, educationists, academia, researchers, curriculum planners and policy makers. The manuscripts can have different approaches which are quantitative as well as qualitative.

IJIS is an annual and peer - reviewed Journal.

Manuscript submitted to IJIS should:

1. have a strong introduction that clearly states the organizing points of the study, acquaints the readers to what is ahead, and makes a direct link between theory, questions and research design
2. have focused literature review that clearly establishes why the topic /problem warrants discussion
3. be prepared according to the style prescribed by the 6th or 7th edition of publication manual of American Psychological Association.

Guidelines for Paper Submission

- * Articles should not be longer than 15 A4 - sized pages using Times New Roman, font size of 12. Longer articles will attract additional publication fee.
- * Reference style should conform to the American Psychological Association format (6th or 7th Edition). This should be arranged in alphabetical order according to the surname of the author.
- * Footnotes are not allowed.
- * Manuscripts' cover should include the title of the paper, author(s) name(s), institution affiliation, contact and E-mail address (es).
- * Abstract should not be more than 250 words.
- * Articles can be submitted electronically via e-mail to ijisn.2023@gmail.com
- * Assessment fee of ₦6,000 shall be paid before any paper shall be reviewed.
- * Publication fee of ₦35,000, is a condition for publication that a manuscript submitted to Ife Journal of Integrated Science (IJIS) has not been published and will not be simultaneously submitted or published elsewhere.

All fees must be paid into Ife Journal of Integrated Science Account.

Bank Name: Polaris Bank

Account Name: Ife Journal of Integrated Science (IJIS)

Account Number: 1140280175

- * Submissions are published at the editor's exclusive discretion. Submission that does not conform to these guidelines may not be considered for publication.

EDITORIAL BOARD

Prof. P. O. Jegede
Editor - in - Chief

Prof. T. O. Bello
Managing Editor

Editors

Prof. O. S. Agboola
Dr. S. O. Olajide

EDITORIAL CONSULTANTS

- Prof. A. Akinlua - Dept of Chemistry, Obafemi Awolowo University, Ile-Ife.
Prof. O. A. Ogunfowokan - Dept of Chemistry, Obafemi Awolowo University, Ile – Ife.
Prof. T. O. O. Oladipupo - Dept. of Botany, Obafemi Awolowo University, Ile – Ife
Prof. J. G. Adewale - Institute of Education, University of Ibadan, Ibadan
Prof. M. A. Eleruja - Dept. of Physics, Obafemi Awolowo University, Ile -Ife.
Prof. M. A. Adeleke - Dept. of Science and Technology Education,
Obafemi Awolowo University, Ile – Ife.
Prof. O. A. Sofowora - Dept. of Educational Technology and Library Studies,
Obafemi Awolowo University, Ile – Ife
Prof. I. A. Olaosun - Dept. of English, Obafemi Awolowo University, Ile – Ife
Prof. D. Okunoye - Dept. of English, Obafemi Awolowo University, Ile – Ife.
Prof. E. T. O. Babalola - Dept. of English, Obafemi Awolowo University, Ile – Ife.
Prof. M. A. Ajayi - Dept. of Human Kinetics and Health Education,
University of Ibadan, Ibadan.
Prof. J. B. Bilesanmi - Dept. of Curriculum Studies and Instructional Technology,
Olabisi Onabanjo University, Awoderu Ago-Iwoye
Prof. A. T. Akande - Dept. of English, Obafemi Awolowo University, Ile – Ife
Prof. E. F. Bamidele - Dept. of Science and Technology Education,
Obafemi Awolowo University, Ile-Ife.
Prof. R. O. Ogunlusi - Dept. of Chemistry, Obafemi Awolowo University, Ile-Ife
Dr. A. Tella - Dept. of Science and Technology Education,
University of Ibadan, Ibadan
Dr. A. S. Adelokun - Department of Educational Management
Dr. K. A. Aderounmu - Department of Kinesiology and Human Recreation,
Obafemi Awolowo University, Ile-Ife.
Dr. T. A. Adebisi - Dept. of Science & Technology Education, Faculty of
Education, Obafemi Awolowo University, Ile-Ife.
Dr. A. A. Adetunji - Dept. of Science and Technology Education,
Obafemi Awolowo University, Ile-Ife.
Dr. V. O. Animola - Dept. of Integrated Science, Federal College of Education,
Iwo, Osun State.
Dr. O. O. Bakare - Institute of Education, Obafemi Awolowo University, Ile-Ife
Dr. M. O. Omiyefa - Institute of Education, Obafemi Awolowo University, Ile-Ife
Dr. V. B. Olanipekun - Bamidele Olumilua University of Education, Science and
Technology, Ikere, Ekiti State.

TABLE OF CONTENTS

INFLUENCE OF TEACHERS' QUALIFICATION ON SENIOR SECONDARY SCHOOL STUDENTS' ACADEMIC ACHIEVEMENT IN CHEMISTRY IN IFE-EAST LOCAL GOVERNMENT AREA OF OSUN STATE, NIGERIA Timilehin Christianah ADEDEJI	1-18
ASSESSMENT OF CHEMISTRY CURRICULUM IMPLEMENTATION IN SENIOR SECONDARY SCHOOLS IN IFE CENTRAL LOCAL GOVERNMENT AREA OF OSUN STATE Elijah Oluwatobi ADEWUYI	19-41
LOCUS OF CONTROL AND SELF-EFFICACY AS PREDICTORS OF SENIOR SECONDARY SCHOOL STUDENTS' ACADEMIC ACHIEVEMENT IN CHEMISTRY IN IFE CENTRAL LOCAL GOVERNMENT AREA, OSUN STATE, NIGERIA Olamide Rofiat TIJANI	42-60
EFFICACY OF SELF-DIRECTED AND COLLABORATIVE CONSTRUCTIVISM INSTRUCTIONAL STRATEGIES ON JUNIOR SECONDARY SCHOOL STUDENTS' ENGAGEMENT IN BASIC SCIENCE AND TECHNOLOGY IN ADAMAWA STATE Samuel Akinola OGUNDARE, Ph.D, & Ahmed IBRAHIM, Ph.D	61-75
EFFECTS OF JIGSAW COOPERATIVE INSTRUCTIONAL STRATEGY ON SECONDARY SCHOOL STUDENTS' ACQUISITION AND RETENTION OF MATHEMATICS PROCESS SKILLS Lucy ERAIKHUEMEN, Peter Akpojehih Agbarogi & Festus Osadebamwen Idehen	76-93

EFFECTIVENESS OF FLIPPED AND BLENDED CLASSROOM LEARNING APPROACHES ON STUDENTS' ACHIEVEMENT IN GENETICS CONCEPTS IN BIOLOGY Blessing Izehiuwa EDOKPOLOR, C. N. OMOIFO, Ph.D & L. ERAIKHUEMEN, Ph.D	94-111
EFFECTS OF FLIPPED AND BLENDED CLASSROOM LEARNING APPROACHES ON STUDENTS' RETENTION IN GENETICS CONCEPTS IN BIOLOGY IN EGOR LOCAL GOVERNMENT AREA OF EDO STATE L. ERAIKHUEMEN, Ph.D, C. N. OMOIFO, Ph.D & Blessing Izehiuwa EDOKPOLOR	112-130
SUSTAINABLE STEM EDUCATION IN THE IOT ERA: BALANCING THE PARADOX OF APPLICATIONS, BENEFITS, AND CHALLENGES FOR BETTER PROSPECT Ezekiel Adedayo ADEOLA	131-157
TEACHERS' TEACHING METHOD PREFERENCES AND RESOURCES UTILISATION AS PREDICTORS OF SENIOR SECONDARY SCHOOL STUDENTS' ACADEMIC ACHIEVEMENT IN CHEMISTRY IN OSUN STATE, NIGERIA Damilola Monsurat ELUYERA & Omowunmi Sola AGBOOLA, Ph.D	158-188
ENVIRONMENTAL LITERACY AMONG OSUN STATE CLASSROOM TEACHERS Omowunmi Sola AGBOOLA, Ph.D, Simeon Olayinka OLAJIDE, Ph.D, Olusegun Ojo BAKARE, Ph.D & Muraina Olugbenga OMIYEFA, Ph.D	189-207
EFFECTS OF BI-MODAL SCHOOL YARD PEDAGOGY AND GENDER ON SCIENCE PROCESS SKILLS OF PRESCHOOLERS IN OYO STATE, NIGERIA Florence Taiwo. OGUNYEMI, Ph.D. & Fatimah ZAKARIYYAH	208-226

STUDY HABIT AS PREDICTOR OF JUNIOR
SECONDARY SCHOOL STUDENTS' INTEREST IN
BASIC SCIENCE IN IFE CENTRAL LOCAL
GOVERNMENT AREA, OSUN STATE

Oluwaseun Newton AJEWOLE

227-234

ROLE OF SCHOOL FARMS IN DEVELOPING
ENTREPRENEURIAL SKILLS AMONG
SECONDARY SCHOOL STUDENTS IN IFE
CENTRAL LOCAL GOVERNMENT AREA, OSUN
STATE, NIGERIA

**Oluyemisi Dolapo ADISA & Ibironke Ibiwumi
IDOWU**

235-248

TEACHERS' SELF- EFFICACY AND JUNIOR
SECONDARY SCHOOL STUDENTS' LEARNING
OUTCOMES IN BASIC SCIENCE IN
SOUTHWESTERN NIGERIA

**Abosede Adenike OYAGBILE, Ph.D. & Theodora
Olufunke BELLO, Ph.D.**

249-262

**SUSTAINABLE STEM EDUCATION IN THE IOT ERA:
BALANCING THE PARADOX OF APPLICATIONS,
BENEFITS, AND CHALLENGES FOR BETTER
PROSPECT**

Ezekiel Adedayo ADEOLA

Department of Physics,
Adeyemi Federal University of Education, Ondo.
E-mail: rexolorunfemi@gmail.com
Telephone Number: 08160203041

Abstract

The Internet of Things (IoT) has changed multiple facets of life, especially in education. This research examines the Sustainable STEM Education in the IoT Era: Balancing the paradox of applications, benefits, and challenges for better prospect. IoT devices enable dynamic, real-time interactions and foster collaboration between educators and learners, enhancing classroom engagement, deepening students' comprehension, and optimizing resource allocation. The applications and benefits of IoT in STEM education encompass smart classroom, management of Alumni data, Electronic-Learning, digital library, security system, students' health monitoring, students' attendance system, digital whiteboard, data resource management and integrated learning, along with convenient access to resources with IoT technology, enhancing administrative effectiveness, enhancing teaching productivity, enhanced facilities optimization, enhance students' understanding, boost students participation, increase parental involvement, remote monitoring, reforming STEM teaching methodology and so on. Nonetheless, the deployment of IoT in education brings about various challenges, such as high expenses, security issues, insufficient internet connectivity, and health hazards. To tackle these challenges, it is crucial to formulate strategies that deal with these problems, improve human resources' knowledge and skills in IoT technology, and

raise awareness regarding the advantages and drawbacks of IoT technology. The future of IoT in STEM education looks bright, with possible uses in intelligent learning settings, advanced laboratories, and monitoring student health. As IoT technology advances, it is essential to leverage its potential to develop more streamlined, impactful, and student-centered learning environment designed to prepare learners for success in the digital age era. This study suggests allocating resources for teacher training, adopting strong cybersecurity protocols, formulating strategies to tackle challenges, enhancing awareness and teamwork, overseeing and assessing IoT application, creating educational content based on IoT, setting up governance structures for IoT, and encouraging partnerships and collaborations.

Keywords: Internet of Things (IoT), STEM Education, Sustainable, Applications, Benefits and Challenges.

Introduction

Imagine a future where technology seamlessly integrates with education, empowering students to become innovative problem-solvers, critical thinkers, and compassionate leaders. Welcome to the era of Sustainable STEM Education in the IoT age. The Internet of Things (IoT) refers to the interconnectedness of infrastructure linked to the internet (Prihatmoko., 2016). The Internet of Thing (IoT) allows devices and objects to exchange information across various networks, such as mobile phones, tablets, and computers, enabling efficient monitoring and control the Internet-space. The internet of Things has transformed life and educational behavior patterns by creating a more efficient learning environment and changing the educational experience (Hutasoit, Farida, Yulianto, Hartono, & Hendra, 2022). The Internet of Things (IoT) originates from merging two terms: Internet and things (Priyadarshini, Sharma, Sharma, & Cengiz, 2022). The Internet is an expansive network of interconnected computers, smart devices, and modems that communicate through standardized protocols for connected systems. The term 'thing'

serves to denote a tangible object, a concept, or an action in a non-specific manner. Therefore, IoT allows objects or items to transmit and receive information through any network, including mobile phones, tablets, and computers, enabling seamless monitoring and control through the internet-space.

Sustainable education is essential for promoting a sustainable future, yet it is hindered by challenges like poor infrastructure, limited resources, and insufficient awareness and involvement and participation. The concept of "sustainability" refers to the capacity to maintain or sustain practices over time without causing substantial harm to the environment, society, or economy. This principle advocates for fulfilling present needs while safeguarding the ability of future generations to meet their own. According to Sterling, and Orr, (2001), sustainable education seeks to foster a learning environment that emphasizes diversity, nurtures creativity, and encourages active engagement, empowering individuals to embrace sustainable practices. In 2015, the United Nations introduced the Sustainable Development Goals (SDGs), comprising 17 targets aimed at eliminating poverty, safeguarding the environment, and promoting global peace and prosperity to be achieved within the timeline of 2030 (United Nations, 2015)." (United Nations, 2015). Education is a cornerstone of these SDGs, as it supports the success of all other goals and helps in creating a sustainable future. The main objective of sustainable education is to equip individuals with the essential knowledge and skills needed to address the societal and environmental challenges of both the present and the future. Beyond its content, sustainable education encompasses innovative teaching methods, adaptive processes, and supportive learning environments. It requires a shift in educational priorities, the transformation of institutional practices, and collaboration among educators, learners, policymakers, and communities. As a continuous and evolving process, it inspires learners to actively contribute toward building a sustainable future. Sustainable Development Goal 4 focuses on providing inclusive, equitable, and high-quality education, along

with promoting lifelong learning opportunities for everyone. To achieve this, specific targets were set, including leveraging modern technologies to enhance the quality and accessibility of sustainable education (United Nations, 2015). A focus on developing learners' competencies to support sustainable development is a priority in sustainable education. This involves adopting personalized, student-centered approaches and integrating advanced technologies like intelligent tutoring systems (ITSs) to better equip learners for addressing sustainability challenges effectively. In the current era of globalization, the rapid advancement of science and technology is evident, particularly with the increasing prevalence of the Internet (Elinda Erni, Fitri Laeli Jannah, and Mei Oktapiani, 2022). One significant development in this context is the Internet of Things (IoT), which connects countless physical devices globally, enabling them to collect and share data seamlessly. The IoT is a concept that aims to optimize the benefits of internet connectivity (Cornelius Gojono, Andreas Nugraha Kwandy, Febrian Victoria, Febrian Bagas Syachputra, Yosua Kristian Kumemap, and Linda Dwi Anggraini, 2021). It marks a transformative shift in the field of information technology by facilitating efficient data exchange through interconnected computer networks (Sultana Sultana, and Tamanna Tamanna, 2021). The Fourth Industrial Revolution has integrated digital technologies, artificial intelligence (AI), and IoT to create innovative solutions that enhance everyday activities. This revolution combines various essential components to achieve advancements in industry and technology (Ramasamy Venkataraman, Arivukkarasi Uthra, Vaidyanathan Sugumaran, V., Rebecca Irene Minu, and Prithiviraj Chelliah, 2023). Additionally, the internet plays a critical role in transforming education by enabling faster knowledge exchange (Fina Meisarah, Nurhikmah Nurhikmah, Muhammad Salahuddin, Sari Khaerani, Indah Nurlela Sari, Retno Sinaga, and Amalia Iman, 2020) and reshaping STEM education by overcoming traditional classroom boundaries.

The IoT has applications across numerous sectors,

including finance, telecommunications, industry, agriculture, healthcare, and education (Jose Jose, 2018). Educational institutions are increasingly adopting IoT to improve learning environments, benefiting students, teachers, and the overall education system (Joseph DeFranco, and Malak Kassab, 2021). These applications cover a wide range of objectives and approaches to enhance the educational process. Integrating technology into education has the potential to significantly improve learning outcomes by making the process more engaging and effective (Fina Meisarah, Nurhikmah Nurhikmah, Muhammad Salahuddin, Sari Khaerani, Indah Nurlala Sari, Retno Sinaga, and Amalia Iman, 2020). The ongoing evolution of digital technologies has transformed the education sector, particularly during the Fourth Industrial Revolution. This phase is characterized by advanced connectivity, enhanced interaction between digital systems, and progress in artificial and virtual intelligence. The rapid proliferation of digital devices has seamlessly integrated internet connectivity into daily life and education systems (Alam, Kazi Arifuzzaman Shakil, and Sajid Khan, 2020). Digital technology has advanced into the era of the Fourth Industrial Revolution, characterized by improved network connectivity, increased interaction among digital systems, and significant progress in artificial and virtual intelligence. The swift development of digital devices has seamlessly integrated internet connectivity into daily life and educational systems. The rapid advancement of digital devices has resulted in the integration of the internet into everyday life and educational frameworks. The Internet of Things has transformed life and educational behavior patterns by creating a more efficient learning environment and changing the educational experience. Prihatmoko, (2016) mentions that as IoT advances, the internet can additionally serve various functions that aid in education, encompassing the use of the internet for both theoretical and practical learning tasks. Integrating IoT in education enhances campus management, promotes collaboration and interaction, and enables personalized and flexible educational experiences.

The significance of the Internet of Things (IoT) in education especially in STEM education is found in its ability to utilize technology for enhancement, the learning process and address the evolving needs of learners in the digital era (Shahin, Y., 2020). IoT can aid students and teachers in collaborating and communicating during their studies. Learners take part in engaging tasks fostering teamwork and communication abilities through IoT-enabled technologies and platforms (Wang, M., and Zhihan, 2020). The IoT enables parents, teachers, and students to interact in real time, enhancing the overall standard of education quality. The capacity of IoT to transform traditional teaching and learning methods renders it significant in education. Internet of Things. Technology allows educators to offer students customized and adaptable learning settings (Agbo, Oyelere, S. S., Suhonen, and Tukiainen, 2021). The IoT collects vast quantities of data regarding student behavior, performance which can be used to tailor education to fits the needs of each students, boost student motivation and engagement, ultimately improve educational outcomes to make STEM education sustainable. Building on the insights mentioned earlier, the researcher is motivated to explore the applications, advantages, and challenges of integrating the Internet of Things (IoT) into science education. Consequently, the aim of this study is examining Sustainable STEM Education in the IoT Era: Balancing the paradox of applications, benefits, and challenges for better prospect.

Literature Review

The purpose of this literature review is to explore Sustainable STEM Education in the IoT Era, focusing on balancing the complexities of its applications, advantages, and challenges for future development. This study seeks to provide an in-depth understanding of IoT's role in science education and its potential to transform traditional teaching and learning methods. By synthesizing existing research and academic findings, it aims to highlight key milestones in the integration of IoT into STEM education. Additionally, the research examines various IoT

platforms, tools, and technologies utilized in educational contexts, exploring their applications in campus management, instructional practices, and ensuring data privacy and security.

Applications of IoT in STEM Education

The advancement and utilization of technology over time have significantly impacted the field of education. The implementation of the internet in education, referred to as e-learning, stems from the revolution in digital technology. The use of IoT systems in instructional and learning activities aims to provide a more effective and holistic educational experience. IoT is particularly beneficial in high school and university settings, where students can transition from traditional printed textbooks to digital formats. In education, IoT is employed to improve the quality and efficiency of learning within institutions. Its applications span various domains, including education, where it introduces innovative tools and technologies that help both teachers and students achieve their goals. By integrating IoT, the education system becomes more dynamic and adaptive, enhancing learning outcomes. Specific examples of IoT applications in education include:

1. **Smart Classroom:** Today, smart classrooms are a prime example of IoT's impact on education. According to (Mahmood, Raja, Kaur, Kumar, and Nagwanshi, 2022), IoT has the potential to revolutionize educational spaces. Modern smart classrooms are equipped with cutting-edge technologies and tools, driving innovation in educational settings (Zhang, and Li, 2021). In essence, IoT is transforming education by creating interconnected, technology-driven learning environments that enhance the educational experience. Internet of Things (IoT) is transforming education by enabling a more integrated and engaging learning environment. Smart classrooms, equipped with sensors, actuators, and microcontrollers, are a prime example of IoT's application in education. These classrooms utilize a learning management system (LMS) portal, allowing teachers to effortlessly control and

monitor the learning environment through a smartphone or tablet app. This includes regulating room temperature, lighting, and audiovisuals, as well as tracking student performance and providing real-time feedback. The integration of IoT technology in smart classrooms is becoming increasingly essential in today's digital age. This system enables teachers to provide personalized learning experiences, monitor student attendance, and ensure class safety. Furthermore, students can access learning materials effortlessly via the classroom's WiFi network, facilitating a more efficient and effective learning process. Ultimately, IoT-powered classrooms are redefining the educational landscape, empowering students to become more tech-savvy and better equipped for success in the digital era.

2. **Management of Alumni Data:** Unlike schools, campuses typically require alumni information for numerous purposes, including industrial partnerships or community development. Consequently, it is not unexpected that at present, numerous campuses in Indonesia are creating This application provides various services for alumni, such as access to smart library facilities, assistance with administrative tasks like legalization requests, and viewing job opportunities offered by campus partner companies. Additionally, universities can use the application to collect alumni data, share updates about campus events, and engage with alumni more effectively.
3. **Electronic-Learning:** E-learning systems serve as frameworks in the educational process, leveraging information technology and internet access to enhance learning experiences. These systems are designed to make subject matter more accessible and comprehensible (Fitria, 2021; Fitria, Simbolon, and Afdaleni, 2022). The e-learning approach offers several advantages, including flexible study schedules, personalized learning paces,

improved understanding of course content, time and effort efficiency, and access to leading educators in specific fields. The Internet of Things (IoT) further supports remote education by enabling more efficient and personalized learning experiences. With IoT technology, students can access lessons and educational materials anytime and from anywhere, while also participating in real-time interactions with teachers and peers through online learning platforms. IoT addresses the challenges of distance learning by creating platforms for seamless communication and collaboration between students and educators, thereby enriching the learning process. Additionally, e-learning platforms integrate information technology and internet resources to support educational activities. These platforms are structured to help students engage with topics and materials more effectively. Key benefits include flexible schedules, tailored learning paces, enhanced comprehension, conservation of time and energy, access to expert educators, and features such as interactive whiteboards.

4. **Digital Library:** IoT has enabled the development of more efficient digital library systems. These advanced systems allow students to access books and educational materials anytime and anywhere using mobile devices such as smartphones or tablets. Educators can also organize resources in interactive digital formats, making learning more enjoyable for students and positively impacting the future of education. Additionally, the book borrowing process is optimized to facilitate faster transactions and maintain accurate inventory records. With IoT, students can request books remotely and collect them when they visit the school. This system also supports analyzing students' reading preferences and interests conducted using statistics derived from book borrowing via the IoT system. The procedure of borrowing books that has been ongoing is typically focused on speeding up and

simplifying the recording of stock and book transactions. Through IoT, students and parents have the ability to borrow books online and then collect them. Stay alert while at school. The system can also analyze children's reading preferences based on the statistics of borrowed books. The Internet of Things is a crucial trend for libraries, as it can improve Service quality, available facilities, and cost reduction are enhanced when both users and librarians access information through the internet. For instance, international museums utilize cloud computing to provide digital services, manage lighting, and store resources in libraries (Handayani, F., 2019).

5. **Security System:** Ensuring safety within the school environment is a top priority, and IoT technology allows for more efficient management of this concern. IoT systems enable schools to monitor the activities of students and visitors with greater accuracy, even in restricted areas, while maintaining the overall security of the campus. Features such as CCTV cameras and temperature sensors can be integrated into these systems, enhancing the efficiency and sophistication of security monitoring. This approach provides a sense of safety for students, teachers, and the institution as a whole. By utilizing IoT, schools can oversee security and environmental conditions more effectively, incorporating technologies like temperature sensors and security detection systems to maintain a safe educational environment. Moreover, employing technology to track vehicle movement near the school area can help minimize the likelihood of accidents, allowing students to feel more secure and at ease during their time at school. An IoT solution that offers continuous security monitoring allows students to concentrate on their studies without being concerned for their safety.

6. **Students Health Monitoring:** In addition to enhancing security, IoT can serve as a dependable protector of student well-being. This system enables the real-time tracking of students' health by monitoring temperature (smart thermometer), heart rate (oximeter plus), pulse rate (digital pulse meter), blood pressure (Digital blood pressure meter), and respiratory (respiratory rate monitor) (Zhong, C.-L., and Li, Y., 2020). As a result, the school can swiftly recognize new health issues and offer suitable care, ensuring students' health is well preserved. We anticipate that this technology will increasingly be utilized in the educational sector in Nigeria, a country we cherish.
7. **Students Attendance System:** The student attendance system is designed to document attendance during educational activities. Currently, the method for collecting attendance data remains manual, making it vulnerable to data loss and input errors. In the IoT era, monitoring student attendance becomes much more straightforward. Students can simply scan their fingerprints when entering and exiting the classroom. Alternatively, they may be issued chip cards that classroom sensors can detect. The attendance data is stored on a server and can be accessed through both web and mobile application. This allows the student's guardian and the school to access the data in real-time. It is a system that helps in recording student attendance in education. Up to now, the process of collecting attendance data is conducted manually, making it susceptible to data loss and input errors. In the IoT era, managing student attendance will be simplified, as students can simply report electronic absences via their digital devices, like smartphones or laptops, during classes. The information is subsequently stored on the server and will be displayed as either a Web application or a mobile application. This allows students and institutions to access the data in real time. Fingerprints are among the

distinctive human body features that serve the application of fingerprint biometric technology, which uniquely identifies individuals through their distinct fingerprints, can help prevent student attendance fraud. According to researchers Utami, B. R. P., Arimbawa, I. W. A., and Bimantoro, F. (2019), integrating Internet of Things (IoT) technology with fingerprint sensors using the MQTT protocol can enhance attendance monitoring efficiency. This system enables students to scan their fingerprints to enter a classroom, ensuring accurate attendance tracking and promoting classroom safety. Incorrect fingerprint entries will prevent automatic door access. Alternative biometric methods, such as facial recognition or retina scans, can also be employed for attendance tracking.

8. **Digital Whiteboard:** A digital whiteboard, also known as an interactive whiteboard, is a touch screen device that functions like a computer. It allows users to store and retrieve information written on it, making it an effective tool for presentations and learning materials. One of its key features is the ability to record presentations, enabling students to review and reinforce their understanding of the material. The interactive whiteboard offers various features, including:
- Recording software that captures audio and visual elements of presentations
 - Video conferencing capabilities
 - Interactive zoom technology
 - Handwriting recognition, which converts handwritten text into digital text
 - Editing capabilities, allowing users to modify presentations and data directly on the screen
 - Image conversion, enabling users to transform handwritten text into images, such as signatures
 - A cutting system, which allows users to extract specific text from the screen.

9. **Data Resource Management:** The Internet of Things (IoT) has the potential to revolutionize education data resource management by making it more efficient and accessible. For instance, smart library systems enable students to borrow and return books independently, eliminating the need for staff assistance and allowing 24/7 access. Moreover, a centralized database management system allows administrators to access student, faculty, and staff data through a single platform, streamlining data entry and management processes, particularly during recruitment periods.
10. **Integrated Learning:** A hybrid educational method combines traditional classroom teaching with online instruction, offering a flexible and enhanced learning experience. This approach has evolved from e-learning and encourages students to take an active role in their education by seeking out additional online resources. By doing so, students are not solely reliant on the teacher, promoting a more autonomous and engaging learning environment. Furthermore, this method enables educators to continue teaching remotely, increasing accessibility and efficiency in educational institutions.

Benefits of Implementing IoT in STEM Education

Envision a scenario where learners can dive into the complexities of the human anatomy, create groundbreaking answers to issues and work together with classmates worldwide all within the convenience of their own classrooms. Embark on a cutting-edge STEM education journey powered by the innovative capabilities of the Internet of Things (IoT) technology. Utilizing the capabilities of IoT, we can develop engaging, interactive, and inclusive educational experiences that motivate the future generations scientist, technologists, engineers, and mathematicians. Let dive into the fascinating realm of IoT within STEM education and examine its benefits as follows:

1. **Convenient Access to Resources with IoT technology:** With the Internet of Things (IoT), students and educators can seamlessly access a wide range of resources, from databases and printers to educational materials. Access levels are tailored to individual roles and security clearances, eliminating cumbersome approval processes. For instance, students can independently borrow lab equipment through an online inventory system, streamlining the process. The IoT also enables the development of intelligent libraries, which provide students with 24/7 access to library resources, including self-service book checkout and computer usage, even when library staff are unavailable.
2. **Enhancing Administrative Effectiveness:** In an educational setting, IoT can enhance administrative effectiveness by sophisticated technology. Leveraging online platforms and applications can significantly streamline school administration, leading to increased efficiency and productivity. By automating administrative tasks, educators can focus on teaching and learning, ultimately enhancing student understanding and knowledge. This innovative technology has the potential to revolutionize school management, elevating educational standards and demonstrating its effectiveness in real-world settings.
3. **Enhanced Teaching Productivity:** The Internet of Things (IoT) system can significantly streamline administrative tasks for educators and administrators, freeing up time for more critical responsibilities. By automating tasks such as attendance tracking and grade assessment, IoT technology can reduce manual labor and minimize errors. For example, automated attendance monitoring eliminates the need for manual record-keeping, while IoT-based evaluation systems can expedite

feedback to students. Furthermore, IoT technologies can also automate other administrative tasks, such as scheduling and communication, ultimately enhancing the overall efficiency and effectiveness of the educational system.

4. **Enhanced Facilities Optimization:** Implementing an IoT system enables educators and administrators to track and manage classroom resources more efficiently, including textbooks, supplies, and equipment. A connected school management system can monitor resource utilization, sending alerts when items need replenishment, ensuring students have necessary materials for success while minimizing waste. Additionally, IoT technology can oversee and regulate school facilities, such as classrooms, laboratories, and sports facilities, optimizing their use and ensuring they remain functional and beneficial. Overall, integrating IoT systems in education improves resource allocation and management.
5. **Enhance Students' Understanding:** Not all topics can be grasped easily if instructors solely rely on text or images on the chalkboard. Students frequently require practical experience or tangible illustrations on a topic. Complex concepts, such as the inner workings of the human body or celestial mechanics, can be challenging to grasp. However, the integration of IoT technologies, specifically Augmented Reality (AR) and Virtual Reality (VR), offers a promising solution. By leveraging AR and VR, students can engage with interactive, three-dimensional models that simulate the structure and movement of complex systems, such as the human body's internal mechanisms or planetary orbits viewed in three dimensions, to make it appear more genuine and easier to comprehend (Fitria, T. N., 2023). With the Internet of Things, the content can be

presented not just as dull text or writing but can also be in the type of animations, videos, and also educational resources utilizing the cognitive ability (AI). Consequently, the class becomes more engaging and learners are more eager to gain further knowledge.

6. **Boost Students Participation:** The integration of IoT devices in the classroom can lead to more captivating and participatory learning experiences, fostering student engagement and motivation. For instance, educators can utilize interactive displays to present rich multimedia content, such as videos and infographics, to clarify complex concepts. Students can then utilize personal devices to respond to questions, engage in discussions, or participate in interactive exercises that reinforce the lesson. Furthermore, IoT-enabled e-learning solutions can facilitate seamless collaboration and communication among students, enabling real-time project teamwork, idea-sharing, and resource exchange. This dynamic approach to learning can cultivate an environment that encourages active participation, creative problem-solving, and deeper understanding.
7. **Increasing Parental Involvement:** The Internet of Things (IoT) can significantly Engaging parents in their child's education is now more accessible than ever. Advanced digital tools and platforms empower parents to monitor their child's academic journey, offering real-time insights and enabling timely communication with educators. Fostering a stronger relationship between parents and the school. This collaborative approach empowers students to reach their full potential and achieve greater success.
8. **Remote Monitoring:** Remote monitoring enables the supervision of network devices across multiple locations,

allowing for anytime, anywhere access. In educational settings, this feature has extensive applications, such as remotely monitoring laboratory experiments through cameras and sensors, facilitating collective evaluation by students and teachers.

9. **Reforming STEM Teaching Methodology:** Teaching is an art that requires creativity, passion, and dedication. But let's face it, traditional teaching methods can be, well, a bit traditional. That's where the Internet of Things (IoT) comes in - a game-changer that's transforming the way we teach and learn STEM subjects into modern method. The Internet of Things (IoT) is revolutionizing teaching methodologies, enabling educators to create immersive, interactive, and personalized learning experiences. With IoT, teachers can track student progress in real-time, adapt their teaching style to meet unique needs, and make complex concepts come alive with interactive simulations. IoT enhances collaboration, communication, and inclusivity, making learning fun and accessible for all students. By harnessing IoT's power, teachers can unlock new possibilities for student learning, creativity, and success in STEM education at large for sustainability.
10. **Real-Time Usage and Updates:** IoT systems facilitate seamless information sharing among interconnected devices and sensors, enabling real-time tracking and monitoring. For instance, IoT can monitor office equipment usage, such as printer activity, and track personnel movement within a facility using RFID technology. In educational settings, this system can efficiently manage attendance, locate employees and students on campus, and streamline administrative tasks.
11. **Cost Efficiency:** The Internet of Things (IoT) promotes cost efficiency in educational institutions by integrating various equipment, systems, and operations. IoT

technology enables the automation of routine functions, such as regulating lighting and air conditioning, thereby reducing operational costs. By leveraging advanced technologies like temperature sensors and automatic lighting, schools can optimize energy consumption and lower electricity costs. Additionally, IoT facilitates the efficient use of resources like water and fuel, leading to significant reductions in operational expenses. These cost savings can be allocated to enhance the quality of education for students. (Dodds, F., Chopitea, C. D., and Ruffins, R., 2021), IoT Optimize resource usage in educational institutions by implementing efficient systems to track and reduce water and energy consumption.

12. **Enhanced Communication and Cooperation:** IoT devices enable immediate communication and cooperation among instructors and learners, along with interactions among the learners themselves. For instance, an instructor can utilize a smart whiteboard to display content during lessons. Learners are able to utilize their devices to pose inquiries, exchange thoughts, or work together on team assignments. This Technology can simplify the process for educators to engage with their pupils and for pupils to collaborate, no matter the place. It can also assist in breaking down geographical obstacles, enabling learners from various regions of the globe to engage and work together in real-time. In order to develop software with IoT, we must recruit a mobile application development service.

Challenges of using IoT in STEM Education

The internet has significantly influenced numerous aspects, particularly in the field of education. At present, an increasing number of schools and Educational institutions are integrating IoT solutions to elevate the quality of learning. The proliferation of e-learning platforms has transformed the

educational landscape, offering tailored applications for diverse institutions. Educators can leverage this technology to create personalized, data-driven lesson plans, streamlining the educational process and enhancing student outcomes. IoT adoption in education also prioritizes safety and efficiency. However, as reliance on mobile devices and IoT grows, educational networks face increased vulnerability to cyber threats, highlighting the need for robust security measures. The primary dangers to the education system allows us to implement the appropriate tools and methods for every educational institution. This approach allows these dangers to prevent access to crucial data from students, teachers, employees, and others significant matters concerning educational institutions. The education sector still faces several challenges with implementing IoT. Underneath represent certain significant obstacles that educational institutions and average families encounter that obstruct effective IoT applications, namely:

- a. **Elevated cost:** Budget is the priority, implementing IoT technology in education is quite costly due to the high quantity to ensure seamless implementation, it's crucial to have the necessary infrastructure, including both physical devices and digital tools. Additionally, collaborating with a skilled technical team is vital to guarantee the effective deployment and integration of the IoT system.
- b. **Concerns about security and safety:** Ensuring the security of educational institutions' IoT systems is paramount. As cloud-based applications are inherently vulnerable to various cyber threats, the integration of IoT in education amplifies this concern. Therefore, it is vital to prioritize data protection, raise awareness about security best practices, and develop robust backup strategies to mitigate potential risks and attacks.
- c. **Insufficient Internet Connectivity for IoT devices:** Despite widespread internet availability, a significant

number of households, especially those in disadvantaged rural areas, lack access to affordable internet connectivity. This creates a significant barrier for students who are expected to utilize online educational resources outside of the classroom.

- d. **Blue Light:** Prolonged exposure to the blue light emitted by most IoT devices can have detrimental effects on students' eye health and overall well-being. Effective implementation of IoT in schools relies on several factors. Firstly, the preparedness, capability, and willingness of teachers, school leaders, and staff to adapt to change are crucial. Their openness to innovation, creativity, and progressive thinking enables continuous improvement. Secondly, significant initial investment is required to integrate IoT technologies. However, when weighed against the long-term benefits, the costs become negligible. A school leader with a clear vision and mission can address challenges effectively, achieving long-term objectives through phased implementation.

The Prospects of IoT in the STEM Education

Due to the swift advancement as information technology continues to advance, innovative educational solutions will emerge, revolutionizing the learning experience and elevating academic standards. Looking to the future, we can expect transformative developments that will reshape the educational landscape are referred to as Cyber Schools utilizing IoT will arise, including:

1. **Smart School Administration:** Smart School Office is an initiative designed to enhance educational institutions. management simpler. Through the implementation of IoT, every system related to the school needs will be combined into a single entity for easier management.
2. **Intelligent School Transport:** The Intelligent School Transportation system provides a comprehensive platform

for schools, students, and parents to monitor and manage shuttle services. This innovative solution offers real-time updates on schedules, driver information, vehicle details, location tracking, and passenger manifests. Equipped with advanced sensors, the system tracks key metrics such as student attendance, temperature, speed, and vehicle utilization. The collected data is transmitted to a central server for processing and dissemination to parents and educational institutions through a user-friendly online and mobile application.

3. **Intelligent School Facility Administration:** Intelligent School Facility involves deploying sensors in classrooms, the system enables schools to track and adjust key environmental parameters, promoting a healthy and effective learning atmosphere. It seems that the text you provided is incomplete. Could you please provide the full text that you would like paraphrased? illustration to establish the brightness level. In a space, a sensor may be installed that can detect During the execution of the teaching and learning process, what is the present situation? Lighting situation in the room, along with the presence of students. Sure! Please provide the text you would like me to paraphrase. Under these conditions, the sensor will intelligently control the lighting system, automatically turning it on and off as needed. This optimized lighting management enhances the overall teaching and learning environment, while also promoting financial efficiency by reducing energy consumption.
4. **Intelligent Student Well-being:** Intelligent Student Health is a holistic system focused on supporting and tracking the physical, emotional, and mental health of students, capable of tracking health of students. By providing students with a tool that is consistently available while engaged in activities, the system can transmit information regarding students' actions and bodily states.

The system is designed to offer details regarding the distance covered, calories expended, body heat, heart rate, and more. In order to Educational institutions can track the well-being of learners. It seems you've provided only the number.

5. **Intelligent Learning Environment:** A Smart Classroom is a space that is equipped with a a mix of different sensors and devices that can aid in education and educational tasks. Examples of tools and sensors present in the class consist of Thermal Sensors, Environmental Sensors, Smart whiteboards, Presence Tracking systems, and so on.
6. **Intelligent Laboratories:** The Smart Lab concept revolutionizes the research and experimentation process, offering an innovative approach to hands-on learning. By leveraging digital technology, students can now conduct virtual dissections using smartphones or Virtual Reality (VR) glasses, eliminating the need for physical specimens. This immersive learning experience enhances teaching and learning outcomes while optimizing resource allocation and reducing costs.
7. **Intelligent School Eatery:** This is a Smart Cafeteria system is an innovative solution designed to streamline food services, enhance the dining experience, and promote efficiency in school cafeterias, capable of tracking purchasing and the sale of food, what students are allowed to purchase, and the nutritional value of the meals consumed. It will be handled by the system and can subsequently be utilized. through the Smart Student Health system as supplementary information.
8. **Tracking Student Activities:** The Student Activity Tracking system is a comprehensive monitoring solution that enables schools to observe student behavior and movements within and outside the classroom. Leveraging

GPS technology and sensor data, the system provides a detailed record of students' locations and movements, allowing schools to identify potential safety risks and take proactive measures to ensure student well-being.

Conclusion

In conclusion, by harnessing the power of IoT, educators can create innovative, technology-enhanced learning experiences that make STEM concepts more accessible, engaging, and effective for students., improving efficiency, and reducing costs. However, its implementation also poses several challenges, including high costs, security concerns, inadequate internet access, and health risks. To overcome these challenges, it is essential to develop strategies that address these issues, enhance human resources' understanding and competence in IoT technology, and promote awareness about the benefits and risks of IoT technology. Furthermore, successful IoT implementation in education requires a collaborative effort from educators, administrators, policymakers, and technology experts. It is crucial to prioritize teacher training and support to ensure seamless integration of IoT technologies into the curriculum. Additionally, educational institutions, to safeguard sensitive information and prevent unauthorized access, it is imperative that investments be made in comprehensive and resilient cybersecurity solutions. Ultimately, the effective adoption of IoT in education can lead to improved student outcomes, increased efficiency, and enhanced educational experiences. As the education sector continues to evolve, it is essential to harness the potential of IoT to create transformative learning environment that harnesses technology to foster student-centered education, equipping learners with the skills and knowledge necessary to thrive in a rapidly evolving digital world.

Recommendations

Base on the findings the following some prospective recommendations were made:

- 1. Invest in Teacher Training:** Educational institutions

should prioritize teacher training and support to ensure seamless integration of IoT technologies into the curriculum.

2. **Implement Robust Cybersecurity Measures:** Protecting sensitive data requires a proactive approach to cybersecurity, involving the implementation of robust security protocols, regular vulnerability assessments, and employee education to prevent data breaches.
3. **Develop Strategies to Address Challenges:** Educational institutions should develop strategies to address the challenges associated with IoT implementation, including high costs, inadequate internet access, and health risks.
4. **Promote Awareness and Collaboration:** Policymakers, educators, and technology experts should collaborate to promote awareness about the benefits and risks of IoT technology and develop guidelines for its effective implementation.
5. **Monitor and Evaluate IoT Implementation:** Regular assessment and evaluation of IoT initiatives enable educational institutions to identify best practices, address areas of improvement, and make informed decisions that enhance the quality, accessibility, and effectiveness of IoT-driven educational experiences.
6. **Develop IoT-Based Educational Content:** Educational institutions should develop IoT-based educational content that is relevant, engaging, and aligned with learning objectives.
7. **Establish IoT Governance Frameworks:** Educational institutions should establish IoT governance frameworks that outline policies, procedures, and guidelines for IoT implementation and management.

8. **Foster Partnerships and Collaborations:** Educational institutions should foster partnerships and collaborations with technology companies, research institutions, and other stakeholders to leverage IoT technologies and expertise.

References

- Agbo, F. J., Oyelere, S. S., Suhonen, J., and Tukiainen, M. (2021). Scientific production and thematic breakthroughs in smart learning environments: A bibliometric analysis. *Smart Learning Environments*, 8 (1) . <https://doi.org/10.1186/s40561-020-00145-4>
- Alam, M., Shakil, K. A., and Khan, S. (2020). *Internet of Things (IoT): Concepts and Applications*. Springer Nature.
- DeFranco, J. F., and Kassab, M. (2021). *What Every Engineer Should Know About the Internet of Things*. CRC Press.
- Dodds, F., Chopitea, C. D., and Ruffins, R., (2021). *Tomorrow's People and New Technology: Changing How We Live Our Lives*. Routledge.
- Elinda, E., Jannah, F. L., and Oktapiani, M. (2022). Pemanfaatan IOT Berbasis Google classroom dalam Pembelajaran E-Learning. *Prosiding Seminar Nasional Pendidikan Matematika (SNPM)*, 3 (1) , 130 – 138 . <http://fkipunswagati.ac.id/ejournal/index.php/snpm/article/view/946>
- Fitria, T. N. (2021). Implementation of Institution's E-Learning Platform in Teaching Online at ITB AAS Indonesia. *EDUTECH: Journal of Education And Technology*, 4(3), 493–503. <https://doi.org/10.29062/edu.v4i3.157>
- Fitria, T. N. (2023). Augmented Reality (AR) and Virtual Reality (VR) Technology in Education: Media of Teaching and Learning: A Review. *International Journal of Computer and Information System (IJCIS)*, 4(1), 14–25. <https://doi.org/10.29040/ijcis.v4i1.102>
- Fitria, T. N., Simbolon, N. E., and Afdaleni. (2022). Possibility of Metaverse in Education: Opportunity and Threat.

- SOSMANIORA: Jurnal Ilmu Sosial Dan Humaniora*, 1(3), Article 3. <https://doi.org/10.55123/sosmaniora.v1i3.821>
- Gojono, C., Kwandy, A. N., Victoria, F., Syachputra, F. B., Kumemap, Y. K., and Anggraini, L. D. (2021). Penerapan Internet of Things dalam Pembelajaran Daring di Masa Depan untuk Membantu Guru SMA Kalam Kudus. *Prosiding Seminar Nasional Desain Sosial (SNDS)*, 3(1), 14–21. <https://ojs.uph.edu/index.php/SNDS/article/view/3>.
- Handayani, F. (2019). Tren Masif Internet of Things (IOT) di Perpustakaan. *JIPI (Jurnal Ilmu Perpustakaan dan Informatika)*, 4(2), 194–209. <https://doi.org/10.30829/jipi.v4i2.4381>.
- Hutasoit, B., Farida, H., Yulianto, T., Hartono, H., and Hendra, V. (2022). Meneropong Dimensi Internet of Things pada Pembelajaran Pendidikan Agama Kristen. *RegulaFidei: Jurnal Pendidikan Agama Kristen*, 7(1), 22–36. <https://doi.org/10.46307/rfidei.v7i1.76>
- Mahmood, M. R., Raja, R., Kaur, H., Kumar, S., and Nagwanshi, K. K. (2022). *Ambient Intelligence and Internet Of Things: Convergent Technologies*. John Wiley and Sons.
- Meisarah, F., Nurhikmah, Salahuddin, M., Khaerani, Sari, I. N., Sinaga, R., and Iman, A. (2020). *Dunia Pendidikan Indonesia Menuju Era Revolusi 4.0*. CV. AARIZKY.
- Prihatmoko, D. (2016). Penerapan Internet of Things (IoT) dalam Pembelajaran di UNISNU Jepara. *Simetris: Jurnal Teknik Mesin, Elektro dan Ilmu Komputer*, 7(2), 567–574. .
- Prihatmoko, D. (2016). Penerapan Internet of Things (IoT) dalam Pembelajaran di UNISNU Jepara. *Simetris: Jurnal Teknik Mesin, Elektro dan Ilmu Komputer*, 7(2), 567–574. .
- Priyadarshini, S. B. B., Sharma, D. K., Sharma, R., and Cengiz, K. (2022). *The Role of the Internet of Things (IoT) in Biomedical Engineering: Present Scenario and Challenges*. CRC Press.
- Sterling, S. R., and Orr, D. (2001). *Sustainable education: Re-visioning learning and change* (Vol. 6). Green Books for the Schumacher Society Totnes.

- Shahin, Y. (2020). Technological acceptance of the Internet Of Things (IoT) in Egyptian schools. *International Journal of Instructional Technology and Educational Studies*, 1(1), 6–10. <https://doi.org/10.21608/ihites.2020.28215.1003>
- United Nations. (2015). *Sustainable development 17 goals*. Retrieved 05 May 2023 from <https://sdgs.un.org/goals>
- Utami, B. R. P., Arimbawa, I. W. A., and Bimantoro, F. (2019). Sistem Presensi Siswa berbasis Internet of Things menggunakan Sensor Sidik Jari pada SMK Perhotelan 45 Mataram. *Jurnal Teknologi Informasi, Komputer, Dan Aplikasinya (JTika)*, 1(2). <https://doi.org/10.29303/jtika.v1i2.59>
- Venkataraman, R., Uthra, A., Sugumaran, V., Minu, R. I., and Chelliah, P. R. (2023). *Internet of Things*. Springer Nature.
- Wang, M., and Zhihan, L. V. (2022). Construction of personalized learning and knowledge system of chemistry specialty via the internet of things and clustering algorithm. *The Journal of Supercomputing*, 78(8), 10997–11014. <https://doi.org/10.1007/s11227-022-04315-8>.
- Zhang, M., and Li, X. (2021). Design of Smart Classroom System Based on Internet of Things Technology and Smart Classroom. *Mobile Information Systems*, 2021. <https://doi.org/10.1155/2021/5438878>
- Zhong, C.-L., and Li, Y. (2020). Internet of things sensors assisted physical activity recognition and health monitoring of college students. *Measurement*, 159, 107774. <https://doi.org/10.1016/j.measurement.2020.107774>.