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Enhancing IoT Literacy: Assessing the Impact of Educational Interventions on IoT Application Awareness and Understanding Among University Students

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Abstract

The Internet of Things (IoT) is changing modern education by making it possible for students to have individualized, interactive learning experiences, yet many students lack a strong understanding of its technical aspects. This study assessed the impact of educational interventions to enhance University students' awareness and understanding of IoT applications of 258 Information Technology and Computer Engineering students at Bulacan State University – Bustos Campus. Using a mixed-methods design, pre- and post-intervention surveys were conducted alongside lectures, hands-on activities, simulations, and case studies to evaluate learning outcomes. Before the intervention, students claimed they'd been quite aware of IoT in everyday life, but they didn't know much about technical areas pertaining to system architecture and data transfer. Post-intervention findings revealed significant improvements in all learning dimensions. Paired samples t-test results showed enhanced understanding of IoT's role in education ($t = -2.48$, $p = 0.014$), ability to explain real-world applications ($t = -2.65$, $p = 0.009$), knowledge of system components ($t = -4.06$, $p < .001$), and increased confidence in applying IoT in academic and professional contexts ($t = -2.53$, $p = 0.012$). All instructional methods were rated effective, with hands-on activities and lectures emerging as the most impactful in terms of engagement, clarity, retention, and real-world application. Overall, the intervention significantly improved students' IoT literacy, underscoring the importance of combining traditional and experiential learning strategies. These findings support the integration of targeted IoT instruction in higher education to better prepare students for technology-driven careers.

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Introduction

The Internet of Things (IoT) is a network of physical things and gadgets that have sensors and software built into them. These objects and devices can connect to the internet and communicate to each other, allowing them to act on their own and be managed from afar. IoT is still emerging, but it has already changed the infrastructure of smart cities by making them more sustainable, productive, and comfortable to live in. Educational institutions have begun integrating IoT into their learning activities to improve the experiences of students, teachers, and the educational system as a whole. According to McRae et al. (2018), IoT enables advanced services through the interconnection of information and communication technologies, revolutionizing traditional teaching practices and the infrastructure of educational institutions. IoT technology facilitates interaction between people (students and teachers) and physical and virtual objects within academic environments, building smart learning spaces, automating administrative tasks, and delivering personalized learning experiences (Marquez et al., 2016; Mohanapriya & Krishnaveni, 2016).

The Internet of Things is changing education by making learning more fun, making it easier to manage resources, and making classrooms smarter. It provides students and teachers with real-time data, interactive tools, and automated administrative processes (Atzori et al., 2010; Fragou & Mavroudi, 2020; Hasas et al., 2024). However, despite its advantages, IoT also presents challenges such as security risks, data privacy concerns, and increasing dependence on technology. As reliance on technology grows, users must remain in control of their usage, ensuring technology serves them rather than the other way around (Kavyashree et al., 2018). Overcoming challenges like high initial costs and the need for teacher training will be essential to fully harness IoT's potential in education.

The significance of this research is to assess how the educational interventions on university students' awareness and understanding of Internet of Things (IoT) applications. It is of benefit to students, teachers, universities, potential researchers, the IoT sector, and parents. Improved awareness has the potential to enhance academic performance, technical skills, and career preparedness in an increasingly technology-based job market. Effective educational interventions can influence teachers to use evidence-based teaching approaches, map STEM/ICT curricula onto industry needs. Universities can update curricula by integrating IoT applications into appropriate fields, financing infrastructure investments, and enhancing their status as centers of tech innovation.

This study has two hypotheses, the null and alternative. First is null: There is no statistically significant correlation between students' prior technical knowledge and their ability to understand IoT applications after educational interventions. Second is alternative: there is a statistically significant positive correlation between students' prior technical knowledge and their ability to understand IoT applications after educational interventions (Bandyopadhay & Sen, 2011). This part of the study contains all the relevant research and literature that may support the researchers' foremost steps that they will undertake to gather results, data, and findings. Specifically, this section involves information about all the variables used as the study progresses. Thus, these references shall justify all the methods utilized in the research.

In higher education, IoT transforms academic practices through consumer technologies, digital strategies, and visualization innovations, while also raising concerns about privacy and safety (Freeman et al., 2015; Maksimović, 2017). Despite these challenges, IoT holds great potential to enhance educational quality, economic efficiency, and social outcomes within institutions. The Internet of Things (IoT) is revolutionizing education by making lessons more engaging, improving access to resources, and fostering collaboration. Driven by technologies such as artificial intelligence and IoT-enabled tools like smart classrooms and interactive learning platforms, these innovations support students in understanding complex subjects and help educators monitor progress and tailor instruction (Al-Emran et al., 2020; Dake et al., 2023; Rodrigues, 2023).

The integration of the Internet of Things (IoT) in education offers promising opportunities but also faces significant challenges. Key obstacles include insufficient technology infrastructure and a lack of training for educators and institutions. Al-Fuqaha et al. (2022) highlight technological barriers such as limited internet speed, device incompatibility, and low digital literacy among instructors. Similarly, Kurni and Srinivasa (2024) emphasize that institutional unpreparedness, privacy issues, and funding shortages often hinder IoT adoption, recommending strategic investments in teacher training and supportive policies. Security and ethical concerns, including unauthorized access to student data and weak regulatory frameworks, further complicate IoT deployment in academic settings (Islam et al., 2020; Booker et al., 2020).

Collectively, these studies show that although IoT has the potential to revolutionize education, its successful and long-term integration depends on overcoming systemic and infrastructure barriers. As IoT rapidly expands across various sectors—such as smart industries, cities, healthcare, and education, it faces challenges like decentralization, poor interoperability, privacy vulnerabilities, and susceptibility to cyberattacks. To address these issues that concern requires secure and scalable solutions that enhance security to protect the IoT ecosystem (Al-Fuqaha et al., 2015; Sicari et al., 2015).

According to Almaiah et al. (2022), the theory examines educational interventions as predictors of awareness and understanding of IoT applications. This theory emphasizes the benefits of adopting IoT tools in improving learning environments, streamlining classroom management, and enhancing instructional delivery. Exposure to IoT-integrated educational settings, such as smart classrooms and automated attendance systems, not only increases operational efficiency but also fosters deeper understanding of technological applications among students (Alhazmi et al., 2023) . This theory provides a relevant framework for evaluating the role of educational strategies in promoting IoT literacy and engagement within academic settings.

This study applies Rogers' Diffusion of Innovations Theory and Vygotsky's Constructivist Learning Theory to explore how university students develop awareness and understanding of Internet of Things (IoT) applications. Rogers' theory describes the spread of new ideas through five stages knowledge, persuasion, decision, implementation, and confirmation highlighting the importance of structured learning environments and group interaction for adopting IoT innovations. Vygotsky's theory emphasizes active, experiential learning within the Zone of Proximal Development, where students engage in tasks slightly beyond their current abilities. In the context of IoT education. According to Santos et al. (2024) emphasized that IoT can serve an interdisciplinary STEAM educational strategy, supporting hands-on activities, simulations, and collaborative projects that foster deeper understanding and meaningful application of IoT concepts.

Conceptual Framework

The conceptual framework guiding this study shows how educational interventions relate to university students' knowledge and comprehension of Internet of Things (IoT) applications. It highlights how instructional strategies such as lectures, hands-on activities, simulations, and case studies serve as independent variables aimed at enhancing learning outcomes, including IoT awareness, system understanding, concept retention, confidence, critical thinking, and practical application. Moderating factors that could affect how effective these interventions are, like past technical expertise and exposure to IoT, are also considered by the framework used in the study. Grounded in Rogers' Diffusion of Innovations Theory and Vygotsky's Constructivist Learning Theory, the framework supports the use of interactive, contextual learning to improve engagement with emerging technologies.

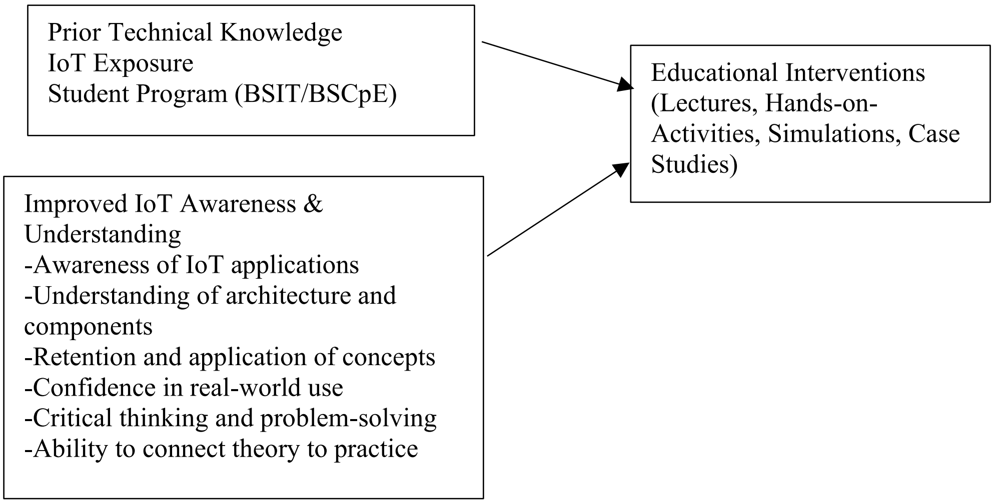

Figure 1. Conceptual Framework showing the Relationship between Educational Interventions and Students' Awareness and Understanding of IoT

Statement of the Problem

This study aims to assess the impact of educational interventions on university students' awareness and understanding of Internet of Things (IoT) applications. It seeks to determine how educational programs influence students' knowledge, perceptions, and readiness to engage with IoT technologies in academic and professional settings.

Specific Problems:

1. What is the current level of awareness and understanding of IoT applications among university students before participating in educational interventions?
2. How effective are educational interventions in improving students' awareness and comprehension of IoT applications?

3. What teaching methods and instructional strategies are most effective in enhancing students' understanding of IoT applications?
4. What are the common misconceptions and challenges faced by students in understanding IoT concepts and applications?
5. Is there a significant correlation between students' prior technical knowledge and their ability to grasp IoT applications after educational interventions?
6. Is there a significant relationship between the type of educational intervention (e.g., hands-on training, online modules, traditional lectures) and students' retention of IoT concepts?
7. What recommendations can be proposed to enhance IoT-related educational interventions for university students?

Method

Research Design

This study employs a mixed-methods design to evaluate the impact of educational interventions on university students' awareness and understanding of IoT applications. The quantitative component uses a correlational approach, administering pre- and post-intervention Likert-scale surveys to measure changes in knowledge, perceived usefulness, and engagement. Descriptive statistics and Pearson correlation coefficients will assess the intervention's effectiveness and the relationships among key variables.

Population and Sampling Respondents of the Study

The study targeted 258 students from the BSIT and BSCpE programs at Bulacan State University – Bustos Campus, with 67.65% enrolled in BSIT and 32.35% in BSCpE. These programs were selected because BSIT and BSCpE students have greater exposure to Internet of Things (IoT) concepts through their coursework, technical training, and project-based activities, making them ideal respondents for assessing IoT awareness and understanding.

Research Instrument

The data gathering tool was a 32-item expert-validated questionnaire designed for survey and statistical analysis. It featured both Likert-scale items and a checklist to assess four main areas: (1) students' initial awareness of IoT in education, (2) the effectiveness of educational interventions in enhancing this awareness, (3) the perceived effectiveness of various teaching strategies, and (4) the identification of common misconceptions and challenges students face when learning about IoT applications.

Data Gathering Procedure

Data was gathered using both online and face-to-face methods to ensure inclusivity. The questionnaire was shared via Google Forms through school communication channels, while printed copies were distributed during class sessions for those without internet access. Researchers assisted without influencing responses, and all completed forms were collected, compiled, and securely stored for analysis.

Statistical Treatment of Data

The data collected were analyzed using both descriptive and inferential statistics. For the demographic profile of the respondents, frequencies and percentages were used to present the distribution of characteristics such as gender, age, and year level. To analyze the Likert-scale items related to students' awareness and understanding of IoT, as well as the effectiveness of teaching strategies, the mean and standard deviation were computed to determine the central tendency and variability of responses. To examine the relationship between key variables, such as IoT awareness and the perceived effectiveness of pedagogical approaches, Pearson's correlation coefficient was applied. All statistical analyses were performed using Jamovi and Microsoft Excel.

Ethical Considerations

Prior to data collection, all participants were fully informed about the purpose and nature of the study and voluntarily provided their consent to participate. To ensure privacy, the respondents' identities remained anonymous, and no personally identifiable information was collected. All data were treated with strict confidentiality and were used solely for research purposes. Measures were taken to securely store and handle the data, protecting the participants' rights and maintaining ethical standards throughout the study.

Results and Discussion

Table 1 shows the distribution of respondents by their course program. Among all the respondents, 174 students (67.4%) are in the Bachelor of Science in Information Technology (BSIT) program, while 84 students (32.6%) belong to the Bachelor of Science in Computer Engineering (BSCpE) program. This means that most of the participants are from the BSIT program, which could imply a greater level of participation or availability of BSIT students in activities concerning the study.

Table 1. Demographics of Respondents

Program	Counts	% of Total
BSIT	174	67.4%
BSCpE	84	32.6%
Total	**258**	**100%**

The balanced distribution from both programs ensures that conclusions are based on a diverse population within the field of technology, making the findings concerning university students' knowledge and awareness of the Internet of Things (IoT) more reliable.

The data in Table 2 reveal that respondents are generally very aware of the Internet of Things (IoT) across multiple dimensions. They show strong awareness of the industries where IoT is applied (M = 3.53, SD = 1.03) and a solid understanding of the basic IoT concept (M = 3.60, SD = 1.20), both rated as "Very Aware."

Table 2. Level of Awareness based on Baseline Knowledge

1.1 Level of Awareness	Mean	SD	VI
1. I am aware of the various industries where IoT is applied	3.53	1.03	VA
2. I understand the basic concept of the Internet of Things (IoT).	3.60	1.20	VA
3. I can name at least one example of an IoT device.	3.68	1.05	VA
4. I can explain how IoT devices collect and transmit data.	3.36	1.10	MA
Avg. Mean	3.54		VA

Legend: *1.00-1.80 NA- Not Aware 1.81-2.60 SA- Slightly Aware 2.61-3.40 MA- Moderately Aware 3.41-4.20 VA- Very Aware 4.21-5.00 EA- Extremely Aware*

Additionally, respondents demonstrate familiarity with practical examples, as reflected by their ability to name at least one IoT device (M = 3.68, SD = 1.05), also categorized as "Very Aware." However, their ability to explain the technical process of how IoT devices collect and transmit data is slightly lower (M = 3.36, SD = 1.10), falling under "Moderately Aware." Overall, these findings suggest that while students have a strong general understanding of IoT, there is room for improvement in deepening their technical knowledge.

Table 3 presents the descriptive statistics of respondents' familiarity with the Internet of Things (IoT). The highest mean score is 3.89 (SD = 1.01) for awareness that IoT is used in daily life, followed by 3.85 (SD = 1.07) for having heard of the term IoT. Respondents also reported familiarity with smart home devices like Alexa (M = 3.76, SD = 1.04) and knowledge of IoT use in transportation, such as GPS (M = 3.70, SD = 1.15). All of these items are rated as "Very Aware" (3.41–4.20), indicating that respondents generally have a strong familiarity with IoT concepts and applications in different areas of daily life.

Table 3. Level of Awareness based on Familiarity

1.2 Familiarity	Mean	SD	VI
1. I have heard of the term Internet of Things (IoT)	3.85	1.07	VA
2. I am aware that IoT is used in daily life (e.g., smart	3.89	1.01	VA
3. I know that IoT is used in transportation (e.g., GPS)	3.70	1.15	VA
4. I have heard of smart home devices (e.g., Alexa)	3.76	1.04	VA
Avg. Mean	3.80		VA

Legend: *1.00-1.80 NA- Not Aware 1.81-2.60 SA- Slightly Aware 2.61-3.40 MA- Moderately Aware 3.41-4.20 VA- Very Aware 4.21-5.00 EA- Extremely Aware*

Table 4 presents the respondents’ level of exposure to the Internet of Things (IoT) across various contexts. The results show that the highest level of exposure is in the use of IoT applications on smartphones, such as home automation and health monitoring apps (M = 3.84, SD = 1.10), followed by the use of IoT-enabled appliances like smart refrigerators, TVs, and security systems (M = 3.83, SD = 1.09). Awareness of smart home devices (e.g., smart lights, thermostats, speakers) also scored highly (M = 3.69, SD = 1.18), as did knowledge of IoT applications in smart cities (e.g., traffic monitoring, waste management) (M = 3.72, SD = 1.05). These items are all rated as "Very Aware" (3.41–4.20). On the other hand, the lowest level of exposure was reported in attending seminars, workshops, or webinars on IoT (M = 3.34, SD = 1.29), which falls under the "Moderately Aware" category (2.61–3.40). Overall, the findings indicate a high level of familiarity with IoT in practical settings, with less exposure to formal learning experiences.

Table 4. Level of Awareness based on Exposure

1.3 Exposure	**Mean**	**SD**	**VI**
1. I have used or owned a smart home device (e.g., smart lights, smart thermostat, smart speaker)	3.69	1.18	VA
2. I have used an IoT-enabled appliance (e.g., smart refrigerator, smart TV, smart security system).	3.83	1.09	VA
3. I have attended a seminar, workshop, or webinar on IoT.	3.34	1.29	MA
4. I am aware of IoT applications in smart cities (e.g., traffic monitoring, waste management).	3.72	1.05	VA
5. I have used IoT applications on my smartphone (e.g., home automation apps, health monitoring apps).	3.84	1.10	VA
Avg. Mean	3.68		VA

Legend: *1.00-1.80 NA- Not Aware 1.81-2.60 SA- Slightly Aware 2.61-3.40 MA- Moderately Aware 3.41-4.20 VA- Very Aware 4.21-5.00 EA- Extremely Aware*

Table 5 presents the respondents' self-reported understanding of IoT in education prior to the intervention.

Table 5. Pre-Intervention Assessment of Respondents' Understanding of IoT Applications in Education

2.1. Pre	**Mean**	**SD**	**VI**
1.The intervention helped me understand the role of IoT in modern education (e.g., smart classrooms, online learning tools).	3.61	1.21	E
2.The intervention effectively explained how IoT can be used to increase student engagement (e.g., interactive boards, smart attendance systems).	3.47	1.08	E
3. I gained knowledge about IoT-based educational platforms (e.g., AI tutors, learning analytics) through the intervention.	3.53	1.09	E
4.The intervention helped me understand how IoT enhances remote learning through connected devices.	3.46	1.12	E
5.The intervention enabled me to explain the benefits and challenges of using IoT in education.	3.44	1.16	E
Avg. Mean	3.50		E

Legend: *1.00-1.80 NE-Not Effective 1.81-2.60 SE- Slightly Effective 2.61-3.40 ME- Moderately Effective 3.41-4.20 E- Effective 4.21-5.00 VE- Very Effective*

The highest mean score is seen in understanding the role of IoT in modern education, such as smart classrooms and online learning tools (M = 3.61, SD = 1.21), followed by gaining knowledge about IoT-based educational platforms like AI tutors and learning analytics (M = 3.53, SD = 1.09). These are both rated as "Effective" (3.41–4.20). Other aspects also fall within the "Effective" category, including understanding how IoT can enhance remote learning through connected devices (M = 3.46, SD = 1.12), and how IoT can increase student engagement using tools such as interactive boards and smart attendance systems (M = 3.47, SD = 1.08). The lowest score is found in the ability to explain the benefits and challenges of using IoT in education (M = 3.44, SD = 1.16), though it still remains within the "Effective" range. These results suggest that even before the intervention, students demonstrated a strong foundational understanding and comprehension of how IoT applies to educational settings across multiple dimensions.

The data in Table 6 reveal that respondents demonstrated a consistently high level of awareness regarding the Internet of Things (IoT) following the educational intervention.

Table 6. Post-Intervention Assessment of Respondents' Understanding of IoT Applications in Education

2.1. Post	**Mean**	**SD**	**VI**
1. I have a clear and comprehensive understanding of what the Internet of Things (IoT) is and how it operates.	3.82	1.05	E
2. I can confidently explain at least three real-world applications of IoT across various industries (e.g., healthcare, smart homes, agriculture) and recognize their impact.	3.69	1.02	E
3. I understand the critical components of an IoT system, including sensors, connectivity, and data processing, and can describe their roles in system functionality.	3.79	1.01	E
4. I am confident in discussing the potential benefits and challenges of IoT, particularly regarding security and privacy concerns, and can analyze their implications for real-world use.	3.74	1.04	E
Avg. Mean	3.74		E

Legend: *1.00-1.80 NE-Not Effective 1.81-2.60 SE- Slightly Effective 2.61-3.40 ME- Moderately Effective 3.41-4.20 E- Effective 4.21-5.00 VE- Very Effective*

The highest mean score is observed in having a clear and comprehensive understanding of what IoT is and how it operates (M = 3.82, SD = 1.05), falling within the "Effective" range (3.41–4.20). Respondents also expressed confidence in explaining real-world IoT applications (M = 3.69, SD = 1.02) and understanding the critical components of an IoT system, including sensors, connectivity, and data processing (M = 3.79, SD = 1.01), both of which are also rated as "Effective".

Additionally, they showed the ability to discuss the potential benefits and challenges of IoT, particularly in terms of security and privacy (M = 3.74, SD = 1.04), and expressed increased confidence in engaging with IoT technologies in academic and professional settings (M = 3.67, SD = 1.17), again falling within the "Effective" category. These findings suggest that the intervention effectively enhanced students' understanding and confidence in dealing with IoT, particularly in terms of practical applications and implications in real-world contexts.

The data in Table 7 reveal that respondents consistently rated the clarity of concepts across different educational methods as “Effective” based on the provided scale. The highest mean score is observed in the clarity of concepts during [Simulation] activities (M = 3.71, SD = 0.989), followed closely by [Hands On Activities] (M = 3.69, SD = 1.054) and [Case Studies] (M = 3.59, SD = 1.014 and M = 3.54, SD = 1.044). All these scores fall within the “Effective” range (3.41–4.20).

Table 7. Effectiveness of Each Pedagogical Approach in terms of Clarity of Concepts

Methods	Mean	SD	VI
1. Lecture	3.69	1.054	E
2. Hands-On Activities	3.71	0.989	E
3. Simulation	3.54	1.044	E
4. Case Studies	3.59	1.014	E
Avg. Mean	3.63		E

Legend: *1.00-1.80 NE-Not Effective 1.81-2.60 SE- Slightly Effective 2.61-3.40 ME- Moderately Effective 3.41-4.20 E- Effective 4.21-5.00 VE- Very Effective*

These findings suggest that the educational methods Hands-On Activities, Simulation, and Case Studies were all effective in delivering clear conceptual understanding to the respondents. The consistency in ratings across these methods indicates that each approach successfully contributed to enhancing clarity of concepts, with Simulations slightly outperforming the others. The small standard deviations further reflect a general agreement among respondents regarding the effectiveness of these methods. Overall, the results highlight that the combination of Hands-on Activities, Simulations, and Case Studies can be an effective strategy for teaching and reinforcing conceptual clarity in educational settings.

The data in Table 8 reveal that respondents consistently rated engagement and interactivity across different educational methods as “Effective,” based on the provided scale (3.41–4.20 = Effective). The highest mean score is observed in [Lecture] (M = 3.76, SD = 0.945), followed closely by [Hands On Activities] (M = 3.72, SD = 1.016), [Case Studies] (M = 3.64, SD = 1.157), and [Simulation] (M = 3.53, SD = 1.044). All scores fall within the “Effective” range.

Table 8. Effectiveness of Each Pedagogical Approach in terms of Engagement and Interactivity

Methods	Mean	SD	VI
1. Lecture	3.76	0.945	E
2. Hands-On Activities	3.72	1.016	E
3 Simulation	3.53	1.044	E
4. Case Studies	3.64	1.157	E
Avg. Mean	3.66		E

Legend: *1.00-1.80 NE-Not Effective 1.81-2.60 SE- Slightly Effective 2.61-3.40 ME- Moderately Effective 3.41-4.20 E- Effective 4.21-5.00 VE- Very Effective*

These findings suggest that lectures were the most engaging and interactive method, though hands-on activities, case studies, and simulations also performed well. The slightly lower score for simulations may indicate room for improvement in interactivity for this method. The varying standard deviations reflect differing levels of consensus among respondents, with lectures showing the highest agreement (lowest SD) and case studies the most variability (highest SD). Overall, the results demonstrate that all four methods lectures, hands-on activities, case studies, and simulations effectively promoted engagement and interactivity, with lectures being the strongest in this category.

The data in Table 9 indicate that respondents consistently rated the retention of information across all educational methods as “Effective,” based on the provided scale (3.41–4.20 = Effective). The highest mean score is observed in [Lecture] (M = 3.78, SD = 1.02), followed by [Hands-on Activities] (M = 3.70, SD = 1.06), [Simulation] (M = 3.67, SD = 1.07), and [Case Studies] (M = 3.55, SD = 1.15). All scores fall within the “Effective” range.

Table 9. Effectiveness of Each Pedagogical Approach in terms of Retention of Information

Method	Mean	SD	VI
1. Lecture	3.78	1.02	E
2. Hands-On Activities	3.70	1.06	E
3. Simulation	3.67	1.07	E
4. Case Studies	3.55	1.15	E
Avg. Mean	3.68		E

Legend: *1.00-1.80 NE-Not Effective 1.81-2.60 SE- Slightly Effective 2.61-3.40 ME- Moderately Effective 3.41-4.20 E- Effective 4.21-5.00 VE- Very Effective*

These findings suggest that lectures were the most effective method for promoting information retention, though hands-on activities, simulations, and case studies also performed well. The slightly lower score for case studies may indicate that this method could benefit from adjustments to further enhance retention. The standard deviations reveal moderate variability in responses, with case studies showing the highest dispersion (SD = 1.15), suggesting less consensus among respondents compared to the other methods.

Overall, the results demonstrate that all four methods lectures, hands-on activities, simulations, and case studies are effective for retaining information, with lectures being the strongest in this category. This aligns with the broader trend observed in the previous tables, where lectures consistently scored highest across multiple dimensions of learning effectiveness.

The data in Table 10 show that all instructional methods—hands-on activities (M=3.84), lectures (M=3.82), case studies (M=3.75), and simulations (M=3.70) were rated as “Effective” for real-world application. Hands-on activities scored highest, suggesting they best bridge theory and practice, while simulations and case studies showed slightly lower effectiveness with more response variability. These findings align with broader trends, reinforcing that experiential methods like hands-on learning are particularly impactful for applied knowledge. All approaches proved viable, with hands-on activities holding a marginal advantage.

Table 10. Effectiveness of Each Pedagogical Approach in terms of Real-World Application

Methods	Mean	SD	VI
1. Lecture	3.82	1.04	E
2. Hands-On Activities	3.84	1.03	E
3. Simulation	3.70	1.04	E
4. Case Studies	3.75	1.19	E
Avg. Mean	3.78		E

Legend: *1.00-1.80 NE-Not Effective 1.81-2.60 SE- Slightly Effective 2.61-3.40 ME- Moderately Effective 3.41-4.20 E- Effective 4.21-5.00 VE- Very Effective*

The data in Table 11 indicate that respondents consistently rated the development of critical thinking skills across all instructional methods as "Effective," based on the established scale (3.41–4.20 = Effective). Hands-on activities received the highest mean score (M = 3.76, SD = 1.09), followed closely by lectures (M = 3.72, SD = 1.12), while simulations and case studies shared identical mean scores (M = 3.60, SD = 1.09 and SD = 1.12, respectively). All methods fell within the "Effective" range, demonstrating their utility in fostering critical thinking.

Table 11. Effectiveness of Each Pedagogical Approach in terms of Critical Thinking Skills

Methods	Mean	SD	VI
1. Lecture	3.72	1.12	E
2. Hands-On Activities	3.76	1.09	E
3. Simulation	3.60	1.09	E
4. Case Studies	3.60	1.12	E
Avg. Mean	3.67		E

Legend: *1.00-1.80 NE-Not Effective 1.81-2.60 SE- Slightly Effective 2.61-3.40 ME- Moderately Effective 3.41-4.20 E- Effective 4.21-5.00 VE- Very Effective*

These results suggest that hands-on activities and lectures were marginally more effective for cultivating critical thinking compared to simulations and case studies. The identical performance of simulations and case studies, coupled with their slightly lower scores, may indicate opportunities to refine these methods—particularly through structured problem-solving frameworks or guided analytical tasks. The similar standard deviations across methods (SD range: 1.09–1.12) reveal comparable levels of respondent consensus, with no method exhibiting pronounced variability.

Overall, the findings underscore that all four approaches effectively promote critical thinking, with hands-on activities and lectures showing a slight advantage. This aligns with prior results, reinforcing the value of active and direct instructional strategies in higher-order skill development. For optimal outcomes, educators might combine hands-on tasks with lectures to leverage their complementary strengths in analytical and conceptual rigor.

The data in Table 12 indicate that respondents consistently rated student participation and Involvement across all instructional methods as "Effective," based on the established scale (3.41-4.20 = Effective). Hands-on activities received the highest mean score (M = 3.79, SD = 0.999), followed closely by lectures (M = 3.78, SD = 1.033), while simulations and case studies shared identical mean scores (M = 3.69, SD = 1.046 and SD = 1.103, respectively). All methods fell within the "Effective" range, demonstrating their utility in promoting student engagement.

These results suggest that hands-on activities and lectures were marginally more effective for encouraging participation compared to simulations and case studies. The identical performance of simulations and case studies, coupled with their slightly lower scores, may indicate opportunities to enhance these methods – particularly through more interactive elements or structured collaborative components. The similar standard deviations across methods (SD range: 0.999-1.103) reveal comparable levels of respondent consensus, with hands-on activities showing the highest agreement (lowest SD).

Table 12. Effectiveness of Each Pedagogical Approach in terms of Student Participation and Involvement

Methods	**Mean**	**SD**	**VI**
1. Lecture	3.78	1.033	E
2. Hands-On Activities	3.79	0.999	E
3. Simulation	3.69	1.046	E
4. Case Studies	3.69	1.103	E
Avg. Mean	3.74		E

Legend: *1.00-1.80 NE-Not Effective 1.81-2.60 SE- Slightly Effective 2.61-3.40 ME- Moderately Effective 3.41-4.20 E- Effective 4.21-5.00 VE- Very Effective*

Overall, the findings underscore that all four approaches effectively promote student participation, with hands-on activities showing a slight advantage. This aligns with prior results, reinforcing the value of active learning strategies in student engagement. For optimal outcomes, educators might combine hands-on tasks with lecture-based discussions to leverage their complementary strengths in fostering both individual and collective involvement.

Table 13 shows that the analysis of instructional methods for teaching complex IoT systems reveals consistent effectiveness across all approaches, with mean scores firmly within the "Effective" range (3.41-4.20).

Table 13. Effectiveness of Each Pedagogical Approach in terms of Understanding Complex IoT Systems

Methods	**Mean**	**SD**	**VI**
1. Lecture	3.74	1.014	E
2. Hands-On Activities	3.75	1.051	E
3. Simulation	3.75	0.991	E
4. Case Studies	3.66	1.102	E
Avg. Mean	3.73		E

Legend: *1.00-1.80 NE-Not Effective 1.81-2.60 SE- Slightly Effective 2.61-3.40 ME- Moderately Effective 3.41-4.20 E- Effective 4.21-5.00 VE- Very Effective*

Hands-on activities (M=3.75, SD=1.051), lectures (M=3.74, SD=1.014), and simulations (M=3.75, SD=0.991) demonstrate statistically equivalent performance, suggesting multiple equally valid pathways for IoT instruction. Case studies, while still effective, show marginally lower results (M=3.66, SD=1.102), potentially indicating room for refinement in their application to technical IoT concepts. Of particular note, simulations emerge as both highly effective and the most consistent method (lowest SD), underscoring their reliability for system-level IoT education.

These findings collectively suggest that IoT instruction benefits from a multimodal approach, where the complementary strengths of hands-on practice for applied skills, lectures for conceptual foundations, and simulations for system visualization can be strategically combined. The results align with contemporary pedagogical research emphasizing the value of diverse instructional methods for teaching complex, multifaceted technologies like IoT systems, while also highlighting the need for careful implementation of case-based learning in technical domains.

The development of problem-solving skills in IoT education demonstrates consistent effectiveness across instructional methods, with all approaches falling within the "Effective" range (3.41-4.20) (see Table 14). Hands-on activities (M=3.79, SD=1.03) and lectures (M=3.76, SD=1.10) emerge as the most effective strategies, suggesting that both experiential learning and structured knowledge transmission contribute significantly to cultivating problem-solving competencies in technical domains. Simulations (M=3.61, SD=1.12) and case studies (M=3.66, SD=1.13) show slightly lower but still substantial effectiveness, potentially reflecting the challenges of adapting these methods to the specific problem-solving demands of IoT systems. The higher standard deviations across all methods (ranging from 1.03 to 1.13) indicate moderate variability in student responses, which may stem from differences in prior technical experience or learning preferences. These findings underscore the particular value of hands-on, practical approaches for developing IoT-related problem-solving skills, while still affirming the important role of traditional lectures in establishing foundational knowledge. The results suggest that an optimal pedagogical strategy might combine hands-on activities with targeted lectures to address both conceptual understanding and practical application, while potentially enhancing simulations and case studies with more IoT-specific problem scenarios to bridge the effectiveness gap. This pattern aligns with constructivist learning theories emphasizing the importance of both active experimentation and structured guidance in developing complex technical competencies.

Table 14. Effectiveness of Each Pedagogical Approach in terms of the Development of Problem-Solving Skills

Methods	Mean	SD	VI
1. Lecture	3.76	1.10	E
2. Hands-On Activities	3.79	1.03	E
3. Simulation	3.61	1.12	E
4. Case Studies	3.66	1.13	E
Avg. Mean	3.71		E

Legend: *1.00-1.80 NE-Not Effective 1.81-2.60 SE- Slightly Effective 2.61-3.40 ME- Moderately Effective 3.41-4.20 E- Effective 4.21-5.00 VE- Very Effective*

The evaluation of students' ability to connect theory to practice reveals that all instructional methods effectively bridge this crucial dimension of IoT education (M=3.67-3.76), with scores consistently within the "Effective" range (3.41-4.20) (see Table 15).

Table 15. Effectiveness of Each Pedagogical Approach in terms of Ability to Connect Theory to Practice

Methods	Mean	SD	VI
1. Lecture	3.71	1.10	E
2. Hands-On Activities	3.76	1.07	E
3. Simulation	3.67	1.12	E
4. Case Studies	3.69	1.10	E
Avg. Mean	3.71		E

Legend: *1.00-1.80 NE-Not Effective 1.81-2.60 SE- Slightly Effective 2.61-3.40 ME- Moderately Effective 3.41-4.20 E- Effective 4.21-5.00 VE- Very Effective*

Hands-on activities demonstrate the strongest performance (M=3.76, SD=1.07), highlighting their natural alignment with practical application, while lectures maintain substantial effectiveness (M=3.71, SD=1.10), suggesting their continued relevance in establishing theoretical foundations. Simulations (M=3.67, SD=1.12) and case studies (M=3.69, SD=1.10) show marginally lower but comparable results, indicating that while these methods successfully connect concepts to application, there may be opportunities to strengthen their practical components. The relatively consistent standard deviations (1.07-1.12) across methods reveal similar levels of student consensus, with hands-on activities showing slightly greater agreement (lowest SD).

These findings emphasize that while all approaches effectively link theory and practice, hands-on methods may offer particular advantages for contextualizing IoT concepts in applied settings. According to Idris et al. (2023), assessment models can improve institutions evaluate their capacity to adopt and sustain IoT based educational technologies. The results support a blended pedagogical approach where lectures establish theoretical frameworks that are then operationalized through hands-on activities, with simulations and case studies providing intermediate application scenarios. This balanced methodology aligns with contemporary educational paradigms that emphasize the importance of both conceptual understanding and practical competence in technical fields like IoT, while also suggesting potential areas for refining simulation and case-based approaches to better mirror real-world IoT implementation challenges.

The evaluation of students' overall" satisfaction reveals that all instructional methods were rated as "Effective" (M=3.71–3.81), with scores consistently within the 3.41–4.20 range (see Table 16). Lectures received the highest satisfaction score (M=3.81, SD=1.06), closely followed by hands-on activities (M=3.79, SD=1.07), while simulations (M=3.73, SD=1.09) and case studies (M=3.71, SD=1.07) showed slightly lower but still strong results. The narrow range of mean scores (difference of only 0.10 between highest and lowest) suggests that all four approaches are comparably satisfying for learners, with lectures and hands-on activities holding a marginal advantage.

The relatively uniform standard deviations (1.06–1.09) indicate consistent agreement among students, with lectures demonstrating the highest consensus (lowest SD). Notably, while hands-on activities scored nearly as high as lectures in satisfaction, their slightly higher variability may reflect diverse student preferences for active learning. Simulations and case studies, though less variable, present opportunities to enhance engagement particularly through more immersive scenarios or real-world case relevance.

Table 16. Effectiveness of Each Pedagogical Approach in terms of Overall Satisfaction with Learning Experience

Methods	Mean	SD	VI
1. Lecture	3.81	1.06	E
2. Hands-On Activities	3.79	1.07	E
3. Simulation	3.73	1.09	E
4. Case Studies	3.71	1.07	E
Avg. Mean	3.76		E

Legend*: 1.00-1.80 NE-Not Effective 1.81-2.60 SE- Slightly Effective 2.61-3.40 ME- Moderately Effective 3.41-4.20 E- Effective 4.21-5.00 VE- Very Effective*

These findings underscore that traditional and experiential methods are both highly valued in IoT education. The strong performance of lectures challenges assumptions that purely technical subjects favor hands-on approaches, while the nearly equivalent satisfaction with active methods supports their growing role in STEM pedagogy. For optimal learning experiences, educators should leverage lectures for foundational clarity while incorporating hands-on and simulated activities for applied engagement. The results advocate for a balanced curriculum that accommodates varied learning preferences while maintaining high satisfaction across all modalities a critical factor in student retention and motivation in complex technical fields like IoT.

The data reveals key gaps in students' understanding of IoT concepts (see Figure 2).

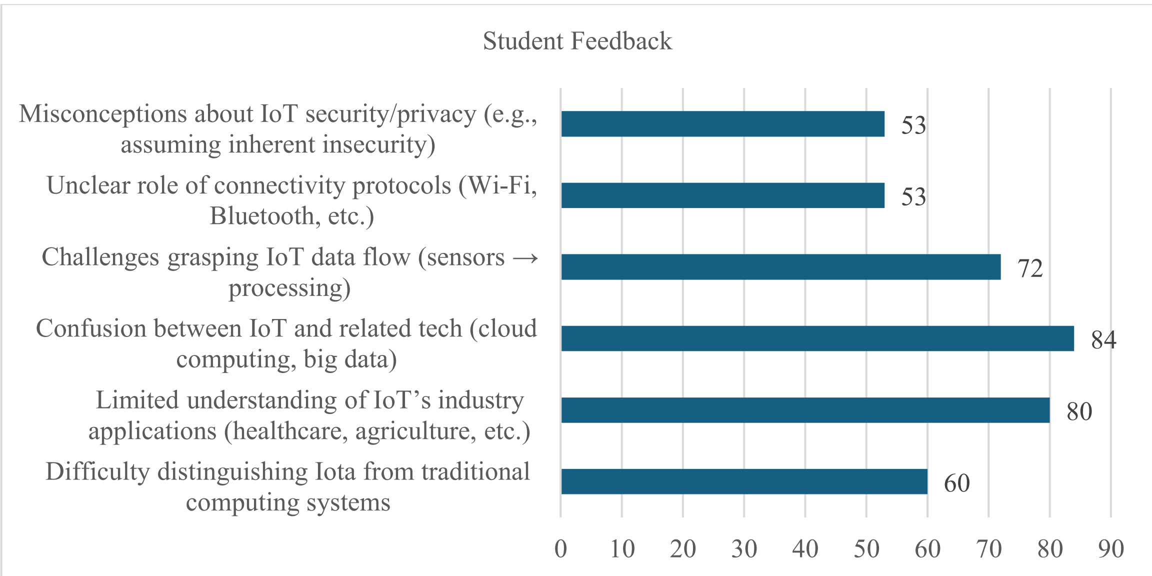

Figure 2. Student Feedback

The most common challenge is confusion between IoT and related technologies like cloud computing (84 students), followed by limited awareness of IoT's real-world applications (80 students). Many students also struggle with fundamental concepts like data flow (72 students) and system architecture. While fewer students report difficulties with connectivity protocols and security (53 each), these remain important areas for improvement. The findings highlight the need for clearer conceptual distinctions, more practical examples, and enhanced visualization of IoT systems in curricula.

The data highlights significant challenges in students' understanding of IoT system fundamentals. The most prevalent issues involve core conceptual gaps, with 91 students struggling to identify basic IoT components (sensors, actuators, connectivity) and 90 students showing unclear understanding of IoT system architecture. Nearly three-quarters of respondents (N=74) cannot adequately differentiate IoT protocols from traditional network protocols, while 66 students remain confused about sensor types and functions (see Figure 3).

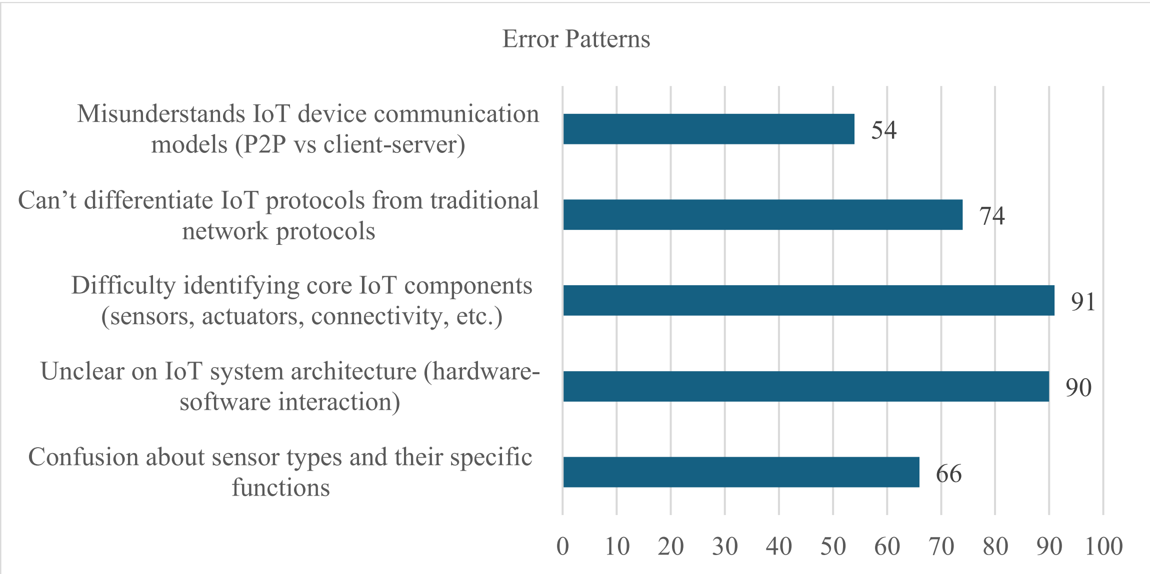

Figure 3. Error Patterns in Assessments in terms of the Internet of Things

Communication models (P2P vs client-server) present the least reported challenge (N=54), though still affecting a substantial portion of learners. These findings reveal critical knowledge gaps in IoT architecture literacy that warrant pedagogical intervention, particularly regarding:

(1) system decomposition and component functions,

(2) protocol-specific knowledge, and

(3) sensor technology applications.

The results suggest the need for enhanced visual scaffolding of IoT architectures and comparative protocol analyses in curricula. Notably, the 54-91 student range across items confirms that while all listed competencies require attention, foundational architecture and component knowledge demand prioritized reinforcement in IoT education. This pattern aligns with broader literature emphasizing architecture literacy as a prerequisite for advanced IoT competencies.

Students face significant difficulties in understanding complex IoT concepts, particularly in distinguishing between real-time and batch data processing (N=76) and recognizing IoT's integration with AI/ML technologies (N=73) (see Figure 4). Additionally, misconceptions about energy efficiency (N=67) and privacy/security implications (N=67) persist. While slightly fewer students struggle with scalability (N=61) and edge computing (N=59), these remain notable gaps. These findings highlight critical areas in IoT education that require focused attention to enhance comprehension of advanced system functionalities and constraints.

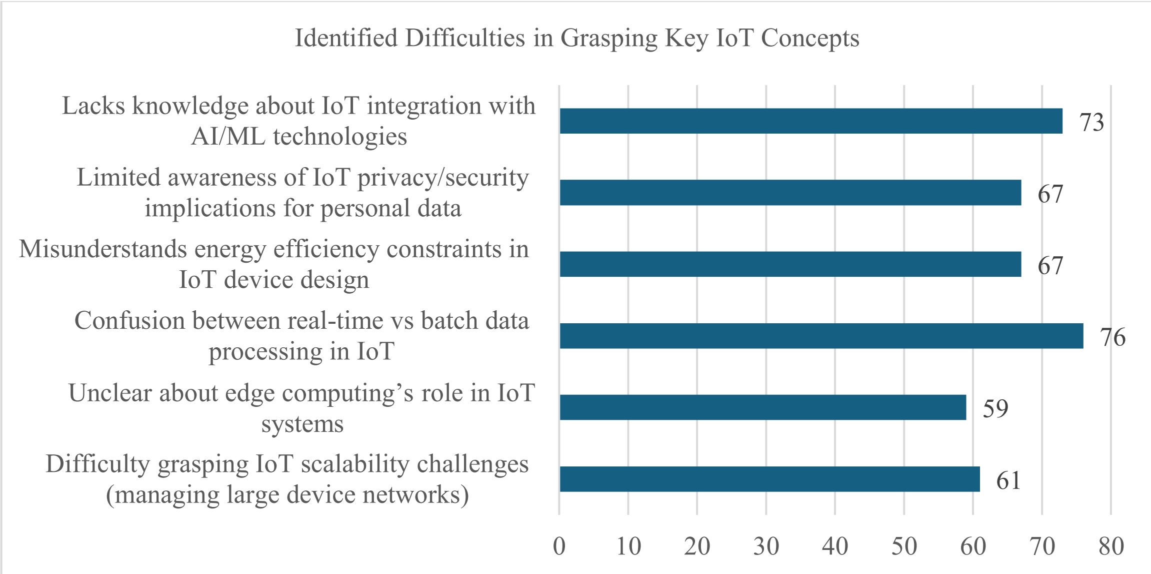

Figure 4. Identified Difficulties in Grasping Key IoT Concepts

Table 17 presents the Pearson correlation between the respondents' pre-intervention and post-intervention self-assessment scores on their understanding of IoT in education. The analysis reveals a moderate positive correlation between the pre-test and post-test mean scores ($r = 0.416$, $p < .001$). This statistically significant result indicates that students who had a higher level of understanding prior to the intervention were also more likely to report higher levels of understanding afterward.

Table 17. Correlation between Respondents' Pre-Assessment and Post-Assessment Scores Following the IoT Educational Intervention

	Correlation	**Pre-Mean**
Post Mean	Pearson's r	0.416
	df	256
	p-value	<.001

The correlation supports the effectiveness of the intervention, as it shows a consistent upward trend in knowledge and confidence from pre- to post-assessment. Moreover, this relationship suggests that the intervention may have reinforced and built upon students' existing foundational knowledge, resulting in a more robust understanding of IoT applications in education.

Table 18 presents One-Way Welch's ANOVA was conducted to determine whether different pedagogical approaches significantly affect students' retention of IoT concepts. The results revealed statistically significant differences across all intervention types: Lecture (p = 0.025), Hands-On Activities (p = 0.007), Simulation (p < .001), and Case Studies (p = 0.004). These findings indicate that the type of educational intervention has a significant impact on students' retention, with simulation showing the strongest effect.

Table 18. Welch's ANOVA Results for Retention Scores Across Educational Intervention Types

Methods	**F**	**df1**	**df2**	**p**
1. Lecture	3.12	4	39.3	0.025
2. Hands-On Activities	4.11	4	38.9	0.007
3. Simulation	7.45	4	39.1	<.001
4. Case Studies	4.48	4	39.5	0.004

Limitation

This research study has its limitations; it was only conducted on the students of one satellite campus of Bulacan State University - Bustos Campus. Being a satellite campus, it might be limited in access to high-technological infrastructure, dedicated laboratory facilities, and exposure to IoT applications on the industry level as compared to primary campuses or bigger organizations. Such constraints might affect the richness of the practical experiences of the students and may have impacted their degree of knowledge and interest in the concepts of IoT regardless of the education interventions used.

Moreover, the results of this research could have had very low generalizability to other campuses or universities with varying resources and academic conditions, as well as student populations. As the sample was limited to a particular satellite campus environment, it did not introduce differences in institutional support, technological preparedness, and integrating curriculum to other campuses. Further research can take into account the idea of using more than one campus or an institution to introduce a more adequate and comparative analysis of IoT awareness and the learning outcomes (Janpirom et al.,2025).

Conclusion

This study explored students' awareness, understanding, and engagement with the Internet of Things (IoT), particularly in the context of education. The findings reveal that students are generally very aware of IoT, especially in practical, everyday applications such as smart devices, transportation, and mobile technologies. Prior to the intervention, respondents already demonstrated a solid foundational understanding of IoT concepts, though certain technical aspects and formal learning exposures showed room for improvement.

Following the educational intervention, students' awareness and comprehension of IoT significantly improved, especially in areas involving system components, real-world applications, and security considerations (Chweya, R., 2021). This suggests that structured educational efforts can meaningfully enhance students' readiness to engage with emerging technologies.

Moreover, the study evaluated various instructional methods lectures, hands-on activities, simulations, and case studies across several learning outcomes including conceptual clarity, engagement, retention, critical thinking, real-world application, and overall satisfaction. All methods were consistently rated as *"Effective"* with hands-on activities and lectures frequently leading in performance. These results underscore the importance of integrating both traditional and experiential strategies in teaching complex subjects like IoT.

In summary, this research highlights the effectiveness of combining foundational instruction with active learning techniques to foster both understanding and applied skills in IoT. It recommends adopting a multimodal pedagogical approach that balances theory and practice to optimize student learning and engagement in technical domains. The results of the Pearson correlation analysis indicate a moderate positive relationship between students' pre-assessment and post-assessment mean scores on their understanding of IoT in education ($r = 0.416$, $p < .001$). This statistically significant correlation suggests that students who demonstrated higher levels of understanding prior to the intervention were also more likely to achieve higher levels of understanding afterward. The findings support the effectiveness of the educational intervention, as it appears to have reinforced and expanded upon the students' existing knowledge. These results underscore the importance of building on prior understanding when designing instructional programs aimed at enhancing technological literacy, such as IoT in education.

Recommendations

To enhance students' awareness and understanding of the Internet of Things (IoT), Classroom instruction should also incorporate real-life case studies and examples from smart homes, healthcare, transportation, and urban development to contextualize IoT applications (Gubbi et al., 2013). Also, educational institutions should integrate experiential and contextual learning approaches, including hands-on activities with Arduino or Raspberry Pi, simulations using tools like Cisco Packet Tracer, and project-based learning, all of which reinforce technical and conceptual knowledge (Patel & Patel, 2016; Al-Fuqaha et al., 2015). Additionally, exposure can be deepened through interactive media, guest lectures from industry experts, and guided exploration of IoT-enabled apps and devices.

To further improve students' understanding of IoT applications in education, real-world simulations or project-based learning that involve designing or evaluating IoT-based educational tools can enhance both technical literacy and analytical skills (Al-Fuqaha et al., 2015; Patel & Patel, 2016). Encouraging activities like debates, case studies, and problem-solving tasks related to IoT in education can deepen conceptual comprehension and foster evaluative thinking (Gubbi et al., 2013). Additionally, it is essential to build on the foundational knowledge gained from pre-intervention exposure by incorporating more immersive and reflective learning experiences. While the data indicates that students already found the intervention effective in helping them understand various educational applications of IoT such as smart classrooms, AI tutors, and interactive tools their relatively lower ability to articulate the benefits and challenges of these technologies suggests a need for more critical engagement

(Alhasan et al., 2023).

To further capitalize on the effectiveness of the intervention in enhancing students' understanding of the Internet of Things (IoT), future educational programs should incorporate more interactive and experiential components such as capstone projects, hackathons, or IoT simulations that mirror real-world applications. While the post-intervention results show improvements in conceptual clarity, technical understanding, and awareness of ethical implications rated consistently as *"Effective"* there is room to elevate this to a *"Very Effective"* level by emphasizing hands-on application and critical evaluation of IoT systems (Al-Fuqaha et al., 2015). Incorporating collaborative learning strategies and cross-disciplinary projects can also deepen students' grasp of how IoT intersects with domains like healthcare, agriculture, and smart infrastructure (Gubbi et al., 2013). Furthermore, discussing case studies on security, privacy, and ethical dilemmas related to IoT can enhance their ability to critically assess real-world challenges (Patel & Patel, 2016).

To address these gaps, educators should integrate clearer conceptual distinctions in the curriculum and provide hands-on experiences through simulations and real-life case studies (Al-Fuqaha et al., 2015). Incorporating interactive tools and visual models can also enhance comprehension of IoT architectures and data flow (Ray, 2016). Moreover, scaffolding security and protocol topics with practical examples may reduce student misconceptions. These pedagogical improvements can foster deeper understanding and better prepare students for IoT-related roles in industry.

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