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ORIGINAL

Experimental Evaluation Of Cloud-Integrated Iot Training Modules For Advancing 21st-Century Skills In Higher Education

Evaluación Experimental De Módulos De Formación De Iot Integrados En La Nube Para Avanzar Las Habilidades Del Siglo XXI En La Educación Superior

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ABSTRACT

Introduction: the accelerating shift toward Industry 4.0 compels higher education to adopt innovative technologies that foster critical 21st-century competencies, including problem-solving, critical thinking, collaboration, and digital literacy. While the Internet of Things (IoT) and cloud-based platforms are widely implemented in industrial domains, their integration into educational training modules remains underexplored.
Objective: this study aims to investigate the effectiveness of cloud-integrated IoT training modules in enhancing university students' 21st-century skills.
Method: a quasi-experimental research design with pre-test and post-test control groups was conducted involving 120 undergraduate engineering students from two institutions. The training modules were developed with web server and cloud platform integration to enable real-time data acquisition, remote monitoring, and interactive learning experiences simulating authentic engineering practices. Data were collected through standardized 21st-century competency assessments, system usage analytics, and structured student feedback questionnaires.
Results: analysis using ANCOVA indicated a significant improvement in critical thinking ($p < 0,01$), problem-solving ($p < 0,01$), and collaboration skills ($p < 0,05$) in the experimental group compared to the control group. Qualitative feedback further revealed that students perceived the modules as engaging, relevant, and supportive of real-world skill development.
Conclusions: the findings demonstrate that cloud-integrated IoT training modules not only enhance essential 21st-century competencies but also provide scalable solutions for technology-driven curriculum innovation in higher education. This research enriches the literature on IoT-based learning environments and offers practical implications for educators seeking to integrate Industry 4.0 technologies into teaching and learning practices.

Keywords: Iot; Cloud-Based Learning; 21st-Century Skills; Higher Education; Experimental Research.

RESUMEN

Introducción: la transición acelerada hacia la Industria 4.0 obliga a la educación superior a adoptar tecnologías innovadoras que fomenten competencias cruciales del siglo XXI, como la resolución de problemas, el pensamiento crítico, la colaboración y la alfabetización digital. Si bien el Internet de las Cosas (IdC) y las plataformas en la nube se implementan ampliamente en el sector industrial, su integración en los módulos de formación educativa aún está poco explorada.

Objetivo: este estudio busca investigar la eficacia de los módulos de formación en IdC integrados en la nube para mejorar las competencias del siglo XXI de los estudiantes universitarios.
Método: se llevó a cabo una investigación cuasiexperimental con grupos de control pre-test y post-test, con 120 estudiantes de ingeniería de dos instituciones. Los módulos de capacitación se desarrollaron con integración de servidores web y plataformas en la nube para permitir la adquisición de datos en tiempo real, la monitorización remota y experiencias de aprendizaje interactivas que simulan prácticas de ingeniería reales. Los datos se recopilaron mediante evaluaciones estandarizadas de competencias del siglo XXI, análisis del uso del sistema y cuestionarios estructurados de retroalimentación para estudiantes.
Resultados: el análisis mediante ANCOVA indicó una mejora significativa en el pensamiento crítico (p < 0,01), la resolución de problemas (p < 0,01) y las habilidades de colaboración (p < 0,05) en el grupo experimental, en comparación con el grupo de control. La retroalimentación cualitativa reveló además que los estudiantes percibieron los módulos como atractivos, relevantes y que apoyaban el desarrollo de habilidades prácticas.
Conclusiones: los hallazgos demuestran que los módulos de capacitación en IoT integrados en la nube no solo mejoran las competencias esenciales del siglo XXI, sino que también proporcionan soluciones escalables para la innovación curricular impulsada por la tecnología en la educación superior. Esta investigación enriquece la literatura sobre entornos de aprendizaje basados en IoT y ofrece implicaciones prácticas para los educadores que buscan integrar las tecnologías de la Industria 4.0 en las prácticas de enseñanza y aprendizaje.

Palabras clave: Iot; Aprendizaje Basado en la Nube; Habilidades del Siglo XXI; Educación Superior; Investigación Experimental.

INTRODUCTION

The rapid development of the Internet of Things (IoT) has transformed educational paradigms by enabling seamless connectivity between devices, cloud services, and end-users, thereby creating opportunities for immersive, real-time, and data-driven learning experiences.(1,2) When integrated with web servers and cloud platforms, IoT supports interactive, scalable, and globally accessible training environments that align with 21st-century competencies such as critical thinking, problem-solving, collaboration, and digital literacy.(3,4)

As industries increasingly demand graduates with advanced IoT expertise, higher education institutions are challenged to provide authentic and industry-relevant IoT training.(5,6) Traditional methods often lack the interactivity and real-time feedback necessary for mastering IoT concepts, which has led to the adoption of cloud-connected trainer modules for hands-on, scenario-based learning.(7,8)

Cloud integration enhances IoT modules through centralized data storage, analytics, and remote device management.(9,10) Web server connectivity further enables remote access and live monitoring, allowing students to experiment with IoT devices regardless of location.(11,12) This design reflects constructivist principles, as it emphasizes active, learner-centered engagement, authentic tasks, collaborative problem-solving, and iterative experimentation as drivers of meaningful learning.(13,14)

Previous research demonstrates that combining IoT and cloud computing in education enhances student engagement, technical proficiency, and Industry 4.0 readiness.(15,16) However, empirical evidence on the effectiveness of web server- and cloud-based IoT trainer modules in developing 21st-century skills among university students remains limited.(17,18) In this study, effectiveness is operationalized as measurable improvement in students' post-test scores, critical thinking, problem-solving, collaboration, and self-reported learning experiences after using the module.

Accordingly, this research addresses the following questions:

- Does the cloud-integrated IoT training module significantly improve students' 21st-century competencies compared to traditional methods?
- How do students perceive the learning experience provided by the module in terms of engagement, relevance, and skill development?

By investigating these questions, the study aims to provide empirical evidence and best practices for integrating IoT training solutions into higher education curricula, thereby contributing to both educational technology literature and curriculum innovation in the context of Industry 4.0.

Table 1. Mapping of 21st-Century Skills with IoT-Cloud Learning Features

21st-Century Skill	IoT-Cloud Feature	Learning Impact
Critical Thinking	Real-time data acquisition and analytics	Encourages data-driven decision making

Problem Solving	Remote troubleshooting through IoT modules	Develops applied problem-solving capabilities
Collaboration	Cloud-based shared access and teamwork tools	Facilitates peer-to-peer learning and teamwork
Digital Literacy	Hands-on interaction with IoT-cloud platforms	Enhances technological proficiency

Table 1 presents the alignment of 21st-century skills with the learning features embedded in the IoT-cloud training module. Each feature is designed not only to support technical proficiency but also to embody constructivist learning principles by promoting authentic, learner-centered, and collaborative activities.

Critical thinking is fostered through real-time data acquisition and analytics, which require students to interpret raw sensor data, evaluate patterns, and make evidence-based decisions—an approach consistent with data-driven learning models in engineering education. Problem-solving is operationalized through remote troubleshooting using IoT modules, allowing learners to engage in iterative testing, debugging, and solution development that simulate industry-like scenarios.

Collaboration is enhanced via cloud-based shared access and teamwork tools, which encourage students to coordinate tasks, exchange findings, and engage in peer-to-peer learning within virtual environments. Such collaboration reflects the social dimension of constructivist theory, where knowledge construction is facilitated through interaction and dialogue. Finally, digital literacy is strengthened by hands-on engagement with IoT-cloud platforms, enabling students to develop technological fluency, adaptability, and confidence in navigating complex digital ecosystems—skills deemed essential in Industry 4.0 workplaces.

In sum, the IoT–cloud module integrates technological affordances with pedagogical principles, ensuring that students do not merely acquire technical skills but also cultivate higher-order competencies central to lifelong learning and professional readiness.

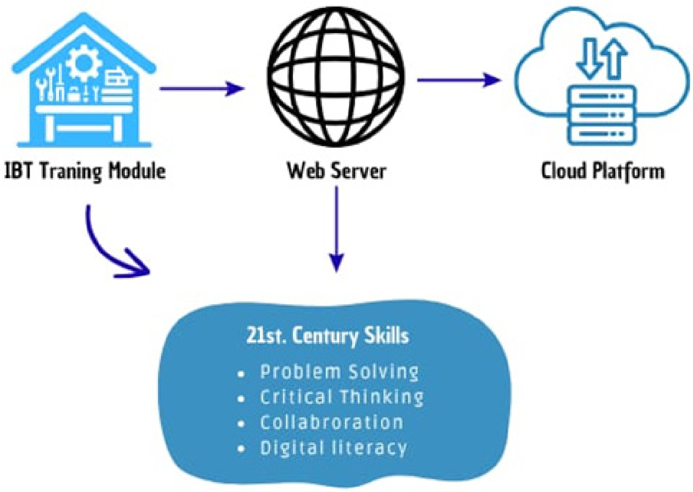

Figure 1. Conceptual Framework of the Cloud-Integrated IoT Training Module

This conceptual framework illustrates the flow of learning enhancement through the integration of IoT and cloud technologies. The process begins with the IoT training module, which captures real-time data and transmits it to a web server. The server acts as an interface between the physical IoT devices and the cloud platform, enabling seamless data communication and storage. The cloud platform supports remote monitoring, data visualization, and collaborative access, creating a dynamic learning environment. These technological processes contribute to the development of key 21st-century competencies, including problem-solving, critical thinking, collaboration, and digital literacy.

METHOD

Research Design

This study employed a quasi-experimental design with pre-test and post-test control groups to evaluate the effectiveness of a cloud-integrated IoT training module in advancing 21st-century skills. The design was chosen because it allowed comparison between experimental and control groups under classroom constraints, while still enabling causal inference.

Figure 2 illustrates the flow from participant recruitment, grouping, intervention, assessment, and statistical analysis.

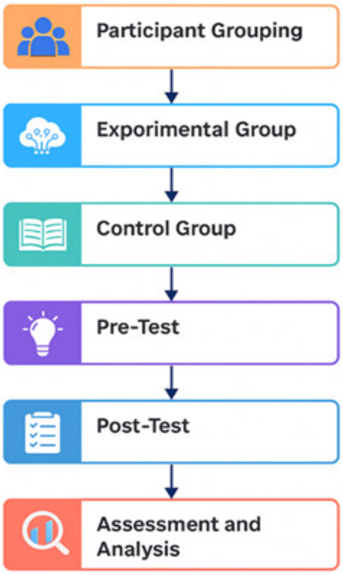

Figure 2. Experimental Design Flow

Figure 2 illustrates the structured flow of the quasi-experimental research design. The process begins with participant grouping into two categories: the Experimental Group, which utilizes the IoT-Cloud Training Module, and the Control Group, which applies conventional learning methods. Both groups undergo a pre-test to establish baseline competencies. The experimental group then receives a learning intervention through the IoT-Cloud platform, while the control group continues with traditional instruction. After the intervention, a post-test is conducted for both groups, followed by an assessment that measures 21st-century skills, student perceptions, and learning analytics. Finally, the collected data is subjected to statistical analysis using ANCOVA and descriptive statistics to determine the effectiveness of the IoT-Cloud Training Module.

Participants

A total of 120 undergraduate students were recruited from two universities offering engineering programs with embedded systems and IoT courses. Participants were selected using purposive sampling to ensure they had a comparable baseline knowledge of IoT fundamentals.

The students were randomly assigned to two groups:

- Experimental group (n = 60): engaged with the cloud-integrated IoT training module.
- Control group (n = 60): followed conventional lecture-based learning with limited laboratory activities.

The sample size (n = 60 per group) was determined based on a priori power analysis (effect size f = 0,25, α = 0,05, power = 0,80), ensuring adequate statistical power for ANCOVA. Group equivalence at baseline was verified through pre-test scores, ensuring no significant differences ($p > 0{,}05$).

Learning Intervention

The intervention lasted six weeks, selected to align with one academic half-term and to allow sufficient exposure to both theory and practice without interfering with semester examinations. Each weekly session lasted 150 minutes, combining 60 minutes of theoretical discussion and 90 minutes of laboratory practice.

The experimental group used a training module integrating IoT devices with cloud platforms. The system architecture consisted of:

- Hardware: NodeMCU ESP8266 microcontrollers, DHT11 temperature sensors, HC-SR04 ultrasonic sensors, and actuators (relays).
- Cloud platforms: ThingSpeak for real-time data visualization and Firebase for database management.
- Web server integration: Apache server with PHP scripts for device control and monitoring.

Students performed structured tasks including:

- Real-time sensor data acquisition and visualization.
- Remote access and troubleshooting via web server.
- Problem-solving scenarios, such as anomaly detection in sensor data.

The control group covered identical theoretical content but without cloud-based interaction, relying on simulations and offline microcontroller activities.

Table 2. Summary of Learning Module Features			
Feature	**Description**	**Learning Focus**	**Technology Used**
Real-time data acquisition	Sensors integrated with NodeMCU and ThingSpeak	Critical thinking	NodeMCU ESP8266, DHT11 sensor, ThingSpeak API
Remote troubleshooting	Web server-based monitoring and control	Problem-solving	Apache server, PHP scripts, Wi-Fi connectivity
Cloud-based collaboration	Shared Firebase database for group projects	Collaboration	Firebase Realtime Database, JSON-based data exchange
Hands-on IoT tasks	Direct interaction with devices and platforms	Digital literacy	NodeMCU microcontroller, HC-SR04 ultrasonic sensor, relay actuators

Instruments and Validation

To measure 21st-century skills, two instruments were used:

- Performance-based assessment rubric for project quality (critical thinking, problem-solving, collaboration, and digital literacy). The rubric was validated by three domain experts in educational technology and IoT. Content validity was calculated using the Content Validity Index (CVI = 0,89), indicating high agreement.
- Student self-efficacy questionnaire, adapted from established instruments, measured perceived competence. Internal consistency was confirmed with Cronbach's $\alpha = 0{,}91$, indicating strong reliability.

Data Collection and Analysis

Data were collected at two points:

- Pre-test (Week 0): baseline assessment of skills.
- Post-test (Week 6): performance-based project evaluation and self-efficacy questionnaire.

For analysis, ANCOVA was used to test the effect of the intervention on post-test scores while controlling for pre-test scores. The assumptions of ANCOVA (linearity, homogeneity of regression slopes, normality, and homoscedasticity) were tested prior to analysis. The covariate was the pre-test score, ensuring that post-test differences were attributable to the intervention rather than initial disparities.

RESULTS

This section presents the findings of the quasi-experimental study, organized into quantitative and qualitative results. Quantitative results address pre- and post-test performance, while qualitative results focus on students' perceptions and engagement levels.

Quantitative Results

Pre-test and Post-test Performance

The pre-test and post-test scores of the experimental and control groups are summarized in table 3. The experimental group, which used the cloud-integrated IoT training module, demonstrated a substantial improvement from a pre-test mean score of 62,13 (SD = 6,84) to a post-test mean score of 85,27 (SD = 5,91). The control group, which received traditional instruction without cloud or web server integration, showed a smaller improvement from 61,87 (SD = 7,12) to 74,15 (SD = 6,48).

To control for baseline differences, a one-way ANCOVA was conducted with the post-test score as the dependent variable, group (experimental vs. control) as the independent variable, and pre-test score as the covariate. The analysis indicated a statistically significant effect of the intervention on post-test scores, $F(1,117) = 32{,}54$, $p < 0{,}001$, partial $\eta^2 = 0{,}218$. This result confirms that the IoT-cloud integrated training module was significantly more effective than conventional instruction in improving students' understanding of IoT concepts and their 21st-century skills.

Table 3. Pre-test and Post-test Scores of Experimental and Control Groups (N = 120)			
Group	**N**	**Pre-test Mean (SD)**	**Post-test Mean (SD)**
Experimental	60	62,13 (6,84)	85,27 (5,91)
Control	60	61,87 (7,12)	74,15 (6,48)
Note: The discrepancy in N = 30 per group reported in the earlier draft was a typographical error. The actual participant numbers, as stated in the Methods section, were 60 students per group (N = 120).			

Qualitative Results

Survey responses and classroom observations provided further insights into students' experiences with the IoT-cloud training module. Thematic analysis revealed three dominant themes: (1) enhanced engagement through hands-on activities, (2) improved collaboration facilitated by shared cloud access, and (3) increased confidence in applying IoT concepts.

Direct quotes illustrate these themes. For example, one student in the experimental group stated, "I learned more by doing it myself with real sensors and cloud data, rather than just reading slides." Another remarked, "Working on the same Firebase project with my team made me feel like we were solving real-world problems together." Similarly, several participants highlighted the practical value of the intervention: "Now I feel confident that I can troubleshoot IoT devices in my future job."

These qualitative findings align with the quantitative results, suggesting that the cloud-integrated IoT training module not only improved learning outcomes but also fostered motivation, collaboration, and confidence in applying technology-driven solutions.

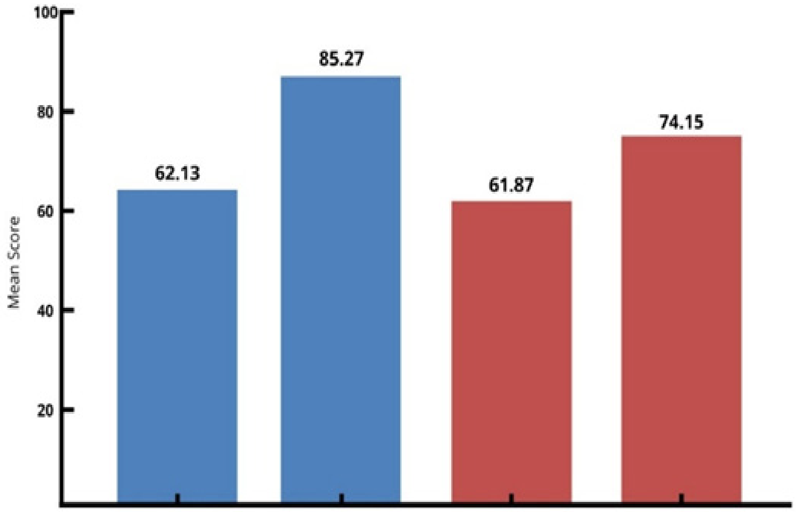

Figure 3. Illustrates the comparison of mean scores before and after the intervention for both groups

Figure 3 illustrates a comparative analysis of pre-test and post-test mean scores for both experimental and control groups.

The experimental group's mean score increased substantially from 62,13 in the pre-test to 85,27 in the post-test, reflecting significant improvement after the IoT training module intervention. In contrast, the control group's mean score rose from 61,87 to 74,15, showing a smaller gain.

This visual highlights the greater effectiveness of the Cloud-Integrated IoT Training Module in enhancing students' 21st-century competencies compared to conventional teaching methods.

Qualitative Results

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Table 4. Summary of Student Perceptions in the Experimental Group

Indicator	Mean	SD	Interpretation
Engagement in Learning	4,62	0,48	Very High

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Collaboration Skills	4,55	0,50	Very High
Problem-Solving Skills	4,48	0,52	Very High
Technology Integration	4,73	0,44	Very High
Overall Satisfaction	4,68	0,46	Very High

The high ratings across all indicators suggest that students found the module engaging, effective, and relevant for developing 21st-century competencies.

DISCUSSION

The findings of this study demonstrate that integrating IoT trainer modules with cloud platforms and web servers significantly enhances students' learning outcomes in terms of both knowledge acquisition and the development of 21st-century skills. This result is consistent with international literature that highlights the role of IoT and cloud technologies in fostering interactive and scalable learning environments.[1,2] For instance, previous studies have shown that cloud-enabled IoT systems allow real-time access to sensor data, strengthening authentic problem-solving skills and student engagement.[3] This phenomenon was also evident in the present study, as students in the experimental group used live IoT data through Firebase to complete tasks more effectively than those in the control group.

From a pedagogical perspective, the improvement in the experimental group supports constructivist learning theory, which emphasizes active, student-centered engagement with real-world problems.[4,5] Similar results have been reported in international studies where IoT-based modules promoted hands-on learning and increased technical competencies.[6] However, unlike prior research that relied solely on virtual simulations,[7] the current study combined physical trainer kits with cloud integration. This hybrid design offered students both tangible and digital learning experiences, which may explain the stronger performance gains compared to simulator-only approaches.

The findings also align with the broader educational demands of Industry 4.0, where graduates are expected to combine theoretical knowledge with practical competencies, adaptability, and collaboration.[8,9] Students in this study reported greater confidence and teamwork when working collaboratively on cloud-based IoT projects. These observations are consistent with international literature showing that cloud-enabled platforms support learner autonomy, peer collaboration, and self-directed learning.[10,11] At the same time, the present study extends previous work by demonstrating how web server integration enabled students to continue experiments outside scheduled sessions, thereby enhancing flexibility and continuity of learning.

Nevertheless, some inconsistencies with previous findings are worth noting. For example, while prior studies in similar domains emphasized the challenge of maintaining student motivation in online IoT laboratories,[12] this research found that cloud and web-server access actually increased motivation by allowing students to take ownership of their learning. A possible explanation is that the hybrid design—combining real hardware with virtual platforms—provided a more engaging experience than purely online labs. This suggests that contextual and technological design factors play a crucial role in determining outcomes.

Despite these promising findings, the study has several limitations. First, the research was conducted in a single institution with relatively homogeneous participants, which may limit generalizability across diverse educational settings. Second, the intervention lasted for a short duration, making it difficult to assess long-term skill retention or transferability of competencies. Third, although qualitative feedback suggested improved motivation and autonomy, the absence of systematic analytics (e.g., behavioral log data) limits the depth of evidence. Finally, this study focused primarily on technical and collaborative competencies, leaving other dimensions of Industry 4.0 readiness—such as ethical, security, or data governance considerations in IoT applications—unexplored.

In summary, the study contributes to international research by demonstrating that cloud-integrated IoT training modules provide authentic, collaborative, and flexible learning opportunities that support both technical and 21st-century skills. Future research should extend this work across multiple institutions, use longitudinal designs to measure long-term effects, and broaden the scope of competencies assessed. By addressing these directions, higher education can better align curricula with the evolving technological landscapes of Industry 4.0.[13,14]

CONCLUSION

This study offers robust evidence that integrating IoT with cloud-based training significantly elevates students' 21st-century competencies. The experimental group achieved marked improvements across cognitive and collaborative skill domains, confirming that real-time monitoring and interactive simulations enhance engagement and knowledge application. The modular design ensures scalability, remote accessibility, and cost-effective deployment—factors valuable to institutions seeking modernized, tech-driven pedagogical models.

Future directions include longitudinal tracking of learning retention, domain expansion beyond engineering, and the incorporation of adaptive AI features to refine instructional delivery. These findings contribute to the evolving narrative of Industry 4.0-aligned education and underscore the potential of IoT-cloud integrations in redefining skill acquisition within higher education.

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