Online-Journals.org

iJEP International Journal of Engineering Pedagogy

iJEP | eISSN: 2192-4880 | Vol. 14 No. 4 (2024) | OPEN ACCESS

https://doi.org/10.3991/ijep.v14i4.45489

PAPER

Analysing IoT Digital Education: Fostering Students' Understanding and Digital Literacy

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ABSTRACT

This study aims to develop effective strategies for enhancing the digital skills of students specialising in information technology (IT). The study's relevance is justified by the necessity to adjust educational methods to the dynamic development of the Internet of Things (IoT) and digital technologies in general. The object of the study is students at Astana IT University who are studying IT. The experimental group (EG) trains using IoT-integrated digital educational materials (DEMs), while the control group (CG) receives traditional training. Since existing research often omits the synergy between IoT and educational methods, creating a gap in understanding the effectiveness of integrated educational resources, this study applies research methodology, including literature analysis, experimentation, and statistical data analysis. The research results are verified using statistical methods such as the Shapiro-Wilk normality test and F-test. Analysing the mean scores in the experimental and CGs helps measure students' progress in developing digital skills. The study aims to determine the effectiveness of IoT-integrated DEMs in enhancing students' digital skills and to provide a comprehensive understanding of the influence of these educational approaches on IoT learning. The findings will significantly improve educational programs and methodologies in the IT domain in line with current technological advancements.

KEYWORDS

Internet of Things (IoT), digital educational materials (DEMs), literacy skills, longitudinal method, digital literacy

1 INTRODUCTION

Today's concept of digital literacy has undergone a metamorphosis in modern education, manifesting itself as 'new literacy'. It involves a tripartite structure comprising data, technology, and human literacy. Data literacy refers to individuals' capacity to read, interpret, analyse, and utilise information in the digital realm [1], [2], [3]. Technology literacy involves the skilful use of digital tools and technologies such as laptops, mobile phones, the Internet, and digital learning resources similar to digital

Tutkyshbayeva, S., Zakirova, A. (2024). Analysing IoT Digital Education: Fostering Students' Understanding and Digital Literacy. *International Journal of Engineering Pedagogy (iJEP)*, 14(4), pp. 4–23. https://doi.org/10.3991/ijep.v14i4.45489

Article submitted 2023-10-02. Revision uploaded 2024-02-14. Final acceptance 2024-02-14.

educational materials (DEMs) [4], [5], [6]. Finally, human literacy involves the development of soft and complex competencies, including communication, critical and cognitive thinking, collaboration, and innovation [5], [7].

[8] covers the application of the Internet of Things (IoT) in educational processes but does not address methodologies for effective teaching or provide the necessary materials for students to become qualified professionals in this field.

After analysing this study, it became evident that the topic of the IoT in the national context still needs further research. Therefore, there is a need for a more detailed study of this area, particularly focusing on enhancing the quality of educational processes through the use of IoT-integrated digital educational materials.

The proposed solution integrates IoT into the DEM system for implementation in the educational process. IoT-integrated DEMs will contribute to the development of IT skills, which should meet the following requirements:

Problem Solving. IoT applications often involve complex problems that require creative and analytical thinking. Students must enhance their capacity to systematically and logically identify and solve problems.

Abstraction. IoT systems often involve abstract concepts such as data modelling and algorithms. Students need to be able to comprehend and manipulate abstract concepts in order to design and implement IoT solutions.

Critical Thinking. IoT applications often have ethical and social implications. Students should develop the ability to critically evaluate the impact of IoT technologies and make informed decisions.

Creativity. IoT applications often require innovative solutions. Students should develop the ability to think outside the box and find creative solutions to IoT problems.

Meeting the above requirements then becomes achievable by utilising specialised digital solutions. These innovative IoT technologies should meet all the specified requirements for developing information technology (IT) skills.

This paper explores methods for developing IoT-integrated DEMs that support students' mastery of IT skills. The study aims to identify effective instructional strategies using digital educational materials to enhance proficiency in IT skills. The authors are also interested in IoT sensor-based learning approaches that foster a deeper understanding of concepts and the successful application of IT skills in real-world scenarios. As part of the study, the authors also explore which IoT technologies can be used to optimise the educational process and make it more effective in developing IT skills.

To address the research questions, the authors conducted a series of studies on shaping IoT-integrated DEMs that emphasize the development of IT skills through the use of IoT sensors. The study utilised research methodology, which involved literature analysis, experimentation, and statistical data analysis. The research results were verified using statistical methods such as the Shapiro-Wilk normality test and F-test. The study analysed mean scores in the experimental and control groups (CG), which helped measure students' progress in developing digital skills. The findings are expected to significantly enhance educational programs and methodologies in the IT domain.

2 LITERATURE REVIEW

2.1 The necessity to develop IoT-integrated DEMs

The international comparative studies conducted by the Organisation for Economic Co-operation and Development (OECD) indicate that globalisation and integration processes are unifying the educational systems of the future into a single educational smart space. This space prioritises the formation and comprehensive development of human capital in line with the increasing demands of the labour market [1]. The results of international studies such as TALIS (The Teaching and Learning International Survey) and PISA (Programme for International Student Assessment) show a low level of development of fundamental skills among students. These skills include reading ability, mathematical literacy, and critical thinking, which are essential for acquiring deeper knowledge and influencing the capacity for future professional training and the development of future specialists [2]. Moreover, the current level of digitalisation and the widespread use of AI and smart technologies elevate the demands on IT personnel and the educational process, consequently raising the complexity of comprehending educational content [4]. Under such conditions, it is essential to pay special attention to developing fundamental skills in students. These skills are the level of comprehension and mastery of in-depth specialised knowledge within the educational material framework.

One of the priorities and in-demand IT areas is the IoT, which offers a valuable opportunity to enhance the basic and professional skills of IT specialists through training in the design, development, and management of IoT systems [1], [2], [4], [5]. The most important professional skills are programming, data analysis, and cybersecurity competencies, which form the foundation for developing more advanced professional IT skills within the IoT subject area [7], [9].

As highlighted by the President of Kazakhstan, K. J. Tokayev, in his address, the introduction of modern concepts and advanced technologies, such as artificial intelligence, blockchain, IoT, and big data analysis, will significantly change how all sectors function, including education [10]. Various studies also highlight that developing strong IT skills will empower Kazakhstan to enable its students to become innovators and leaders in the IoT revolution. Developing a well-educated and skilled IT workforce will be crucial for the country to harness the opportunities that the IoT offers and build a flourishing digital economy.

So, the rapid growth of digital technologies and the consolidation of IoT within educational settings require a re-evaluation of traditional pedagogical methods. The skilful utilisation of IoT-integrated DEMs has the potential to revolutionise the learning experience, providing students with an enriched, interactive, and immersive mode of education [11], [12].

Therefore, integrating DEMs and the IoT is an essential aspect of educational development that necessitates further in-depth research from a scientific perspective. This issue should be considered in light of previous studies and current trends.

2.2 What are IoT-integrated DEMs?

Digital educational materials such as e-textbooks, interactive applications, and multimedia resources have the potential to enhance the learning process, making it more accessible and engaging. IoT interventions in this context provide opportunities to create intelligent educational environments where the collected data can be used to personalise learning, analyse the effectiveness of teaching methods, and improve the overall efficiency of the educational process.

However, for a thorough discussion on the IoT-integrated DEMs, the following aspects need to be considered: data security, network infrastructure efficiency, methods for analysing the collected data, tailoring content to individual learner needs, and ethical issues.

Consequently, further research and discussion in this area is vital to identify best practices for IoT-integrated DEMs to enhance the quality of education.

To be precise, incorporating IoT-integrated DEMs within the educational framework is crucial for developing digital literacy skills in students. Within the landscape of the Fourth Industrial Revolution, the digital literacy paradigm comprises three main categories: data, technology, and human literacy [13], [14]. Data literacy is the ability to understand, analyse, and effectively utilise information within the digital domain [4], [7]. In the chorus, technological literacy empowers learners to adeptly engage with technologies, including IoT devices and web applications [3], [6], [15], [16]. In contrast, human literacy aims to cultivate intangible competencies, such as soft skills such as communicative competence, critical reasoning, and creativity [16], [17]. IoT-integrated DEMs help foster proficiency that encompasses all three categories of literacy.

Furthermore, integrating IoT into the educational paradigm can help bridge the gap between theoretical knowledge and practical application. By actively engaging with IoT-integrated DEMs, students can gain hands-on familiarity with real-time data manipulation, information analysis, and applying knowledge within real-world contexts. This is because practice makes perfect [13], [18]. Such experiences can significantly enhance their understanding of complex concepts, enabling them to tackle the challenges of the Fourth Industrial Revolution [14] and assisting students in adapting to the advancements of the technological era.

The IoT integration of the physical and virtual worlds creates distinctive educational opportunities. Employing IoT-integrated DEMs enhances students' engagement and learning activities, fostering their competence in data manipulation and technological understanding, and amplifying their soft skills [13], [19], [20].

Integrating the IoT into education can cultivate a culture of continuous learning and adaptability among students [14]. Given the rapid evolution of the digital landscape, students must cultivate a growth-oriented mindset and be open to acquiring new competencies throughout their lifetimes. By engaging in IoT-integrated DEMs, students can nurture their aptitude for self-directed learning, critical thinking, and problem-solving insight—indispensable attributes for thriving in the digital era [21], [22], [23]. DEM's serve as an innovative pedagogical tool that utilises digital technologies to create interactive and dynamically enriched educational content. DEMs synergistically combine various multimedia elements, including video, audio, graphics, interactive tasks, and evaluative assessments. This integration fosters a learning process that is engaging and effective.

While the potential benefits of IoT-integrated DEMs are alluring, it is essential to understand prospective challenges simultaneously [24], [25]. For instance, ensuring equitable access to technology and IoT devices for all students is crucial to preventing the exacerbation of educational disparities [24]. Concurrently, educators require comprehensive training and support to integrate IoT-integrated DEMs into their teaching practices [25]. By incorporating IoT-integrated DEMs into education, educators and learners gain universal access to educational resources at any time and from any location [26], [27]. This pivotal attribute contributes to a more adaptable and personalised learning experience, which becomes essential in the era of the Fourth Industrial Revolution, where digital technologies enhance our living standards [28].

IoT-integrated DEMs enhance students' understanding in various subjects, such as mathematics and engineering, by boosting their learning, motivation, and engagement. This research examines the influence of IoT-integrated digital elevation models DEMs on developing students' conceptual understanding and digital literacy skills. Furthermore, their readiness to navigate challenges in modern educational processes arising from the Fourth Industrial Revolution is assessed.

3 METHODOLOGY

This study employed longitudinal research methods to offer a thorough and comprehensive analysis of changes and trends in the educational environment over time. The central feature of the study was the non-equivalent CG design. It is characterised by grouping two different sample groups drawn from the targeted student population, which allows for a more accurate assessment of the effectiveness and impact of introducing the IoT in the educational process. These groups were classified as experimental and CGs. In the experimental group (EG), participants worked with materials representing the independent variable, utilising IoT-integrated DEMs seamlessly integrated within the pedagogical process, while the CG did not receive supplementary materials. During practical interventions, the EG used DEMs, while the CG worked with conventional teaching materials available within the university's curriculum, such as electronic course materials, syllabi, and others. Table 1 illustrates the structure of this study.

Table 1. Structure of the study

Groups	Standard Study Materials	DEMs
Experimental Group (EG)	+	+
Control Group (CG)	+	–

This specific study design was selected for its capacity to guarantee the reliability of the results and the accuracy of the conclusions drawn regarding the impact of IoT technologies in the educational sphere. It also provides a clear distinction between groups and helps reliably assess the effect of innovative educational methods.

The experiment participants were the students of Astana IT University in Astana. The number of respondents was 197.

The groups were rigorously selected through random procedures (by traditional division), and the mean grades of the students in Learning IoT (Arduino) Sensors and Introduction to Programming 1 ranged from 70.3 to 71.5 and higher, respectively. The assessment tool covers various aspects of technical skills in the IoT domain, including understanding key concepts, programming devices, analysing data, and developing IoT-based solutions.

The groups were meticulously selected through random procedures, displaying average scores of 70.3 and 71.5, respectively. Before initiating the experimental phase, a consensus dialogue was conducted with the students to identify their willingness to participate in the research. Additionally, a Google Form survey was created to evaluate students' comprehension and literacy levels concerning IoT.

The questionnaire contained the following questions:

- Are digital educational materials used in the classroom to teach IT skills?
- Is there integration between programming lessons and lessons using IoT technologies to create complex educational scenarios?
- Do you apply your knowledge of IoT technologies in real-world projects or tasks?
- Do you feel that your current knowledge of IoT is sufficient to solve complex problems?
- How would you rate your programming skills related to IoT devices on a scale of 1 to 10?

Based on the questionnaire results, it was evident that students needed to enhance their technical literacy and acquire relevant skills to effectively utilize IoT sensors in solving complex problems.

This questionnaire facilitated the assessment of students' current readiness to engage with IoT technologies, pinpointing areas of concern where technical literacy and skills require enhancement.

This methodological approach to group stratification, baseline data establishment, and data collection is characterised by stringent structuring, which helps generate reliable results that are genuinely representative of the research's intended outcomes.

The outcomes of the conducted studies reveal that both sample groups showed similar levels of IoT knowledge and literacy at the beginning. No significant differences in pre-existing knowledge or competencies about the subject matter were found between the groups. This discovery is noteworthy as it highlights the comparability of both groups' initial conditions, thus preventing any potential bias that could have influenced the experiment's outcomes. Hence, the uniformity of the study's starting points for both groups confirms the validity and representativeness of the data collected.

The authors divided the students into groups. Group CS-2219-2230 was designated as the EG, while group CS-2231-2239 served as the CG. Randomly assigning students to these dichotomous groups establishes an objective and reliable platform for evaluating the effects of DEMs on IoT comprehension and literacy [29]. This approach negates any predisposed biases associated with pre-existing disparities among student groups, such as variations in prior experiences or knowledge [23], [29]. Consequently, this method fosters an impartial appraisal of the influence of DEMs on pedagogical outcomes, thus facilitating more coherent conclusions regarding their effectiveness within the educational landscape.

In this study, the authors utilised a didactic instrument—IoT-integrated DEMs—developed to enhance students' practical skills in the IoT domain and facilitate the development of digital literacy competencies in this area. The developed DEMs represent a seamlessly integrated pedagogical resource engineered to enhance the comprehension and application of IoT concepts [30]. The core mission of DEMs is to ensure that students have the essential knowledge and skills to interact with IoT technologies while also nurturing new abilities and competencies. The structure of the applied DEMs underwent meticulous scrutiny by experts affiliated with Astana IT University, including candidates in pedagogical sciences, associate professors, and PhD holders from the departments of Computer and Software Engineering and Informatics. These reviewers comprehensively evaluated the educational tool's content, methodology, and structure and assessed its adherence to academic standards and objectives.

Additionally, a concordance coefficient (Cohen's Kappa) was applied to assess the level of agreement and similarly among peer evaluations to enhance the peer review process. This metric helps analyse the degree of consensus between evaluations, shedding light on the uniformity with which reviewers gauge the salient attributes and value of the IoT educational tool (DEMs). The resulting mean concordance coefficient tallied at 0.85, highlighting significant agreement and alignment of viewpoints among reviewers regarding the utility and practical significance of this educational tool.

The input received through reviewers' feedback and recommendations was carefully incorporated to refine and enhance DEMs. The principal objective was to ensure the quality and efficacy of the manual, thereby enhancing its usefulness in supporting pedagogical processes and improving students' skills in the realm of IoT.

The content of IoT-integrated DEMs was meticulously curated to align with educational standards. It encompasses themes and experiments designed to enhance students' practical skills and provide them with new knowledge about the realm of IoT. Figure 1 illustrates the comprehensive outline of this educational tool.

CONTENT

Fig. 1. The content from the IoT-integrated DEMs

Source: Developed by the authors of this paper.

IoT-integrated DEMs encompass 15 distinct experiments, providing sensor names, programme codes for conducting experiments, and additional materials for students. Such supplementary materials enable students to independently design and carry out their experiments based on the objectives and expected results specified in the educational tool.

Each experimental exercise within DEMs is categorised according to complexity levels: moderate and challenging. This split facilitates the assessment of students' practical levels, customising the tasks according to their needs and proficiencies. Figure 2 below presents Experimental Exercise No. 5 (Practical Work) and its structure.

5 Practical work
«Unauthorized intrusion»
Level:**

Purpose: Use an ultrasonic sensor to detect an intruder. Connect the intrusion sensor to the servo and LEDs so that when someone comes within a certain distance, the green LED turns off, the red LED turns on and the servo moves.

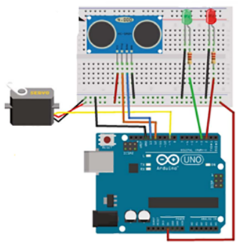
Tasks

1. To study the principle of operation of the ultrasonic sensor and its ability to detect motion.
2. Assemble the necessary equipment, including the ultrasonic sensor, microcontroller and connecting wires.
3. Program the microcontroller to work with the ultrasonic sensor and process the received data.
4. Connect the ultrasonic sensor to the microcontroller and check its performance.
5. Develop an intruder detection algorithm based on the data received from the ultrasonic sensor.
6. Configure the system so that it can send notifications or signal when an intrusion is detected.
7. Test the system using various intrusion simulation scenarios.
8. Evaluate the effectiveness and reliability of the intruder detection system.
9. Carry out the necessary improvements and improvements to the system, if necessary.

Required Parts:

Arduino board
Layout
Wire jumpers
Four-pin ultrasonic sensor HC-SR04
Servo motor
Red LED
Green LED
2 resistors of 220 om

Scheme:



Program code:

```
#include <NewPing.h> // Including the NewPing library
#include <Servo.h> // Including the Servo library
#define trigPin 12 // Trig pin connected to Arduino pin 12
#define echoPin 13 // Echo pin connected to Arduino pin 13
#define MAX_DISTANCE 500
NewPing sonar(trigPin, echoPin, MAX_DISTANCE); // Library setup
int greenLed = 3, redLed = 2; // Green LED on pin 3, red on pin 2
int pos = 20;
Servo myservo;
void setup() {
  Serial.begin(115200);
  pinMode(trigPin, OUTPUT);
  pinMode(echoPin, INPUT);
  pinMode(greenLed, OUTPUT);
  pinMode(redLed, OUTPUT);
  myservo.attach(9); // Servo connected to pin 9
}
void loop() {
  int duration, distance, pos = 0, i;
  digitalWrite(trigPin, LOW);
  delayMicroseconds(2);
  digitalWrite(trigPin, HIGH); // Trig-pin sends an ultrasonic signal
delayMicroseconds(10);
  digitalWrite(trigPin, LOW);
  duration = pulseIn(echoPin, HIGH); // Echo pin receives a response
  distance = (duration / 2) / 29.1;
  Serial.print(distance);
  Serial.println(" cm");
  // If the sensor detects an object within 15cm
```

Fig. 2. Experimental exercise no. 5

Source: Developed by the authors of this article.

The research phase consisted of three sequential stages. Initial preparations constituted the first phase, involving the preparation and compilation of all necessary elements for this study. The second phase involved implementing the chosen research approach in both selected groups, specifically teaching IoT-integrated DEMs to the EG. The final phase involved developing a study report.

3.1 Data collection and instrument

A variety of methods, including both traditional and contemporary approaches, were used to assess students' literacy in this area.

The new instrument for evaluating IoT student literacy has been meticulously devised to assess students' proficiency and comprehension within this significant domain. This educational tool is an assessment grid that includes a variety of components, indicators, and explanations, all designed to evaluate students' competencies and knowledge in the realm of IoT.

The grid of this innovative tool, designed to assess student literacy in the IoT realm, consists of the following components:

Area of Evaluation: This section defines the main area of expertise that the tool focuses on, which, in this case, relates to IoT.

Assessment Categories: The assessment grid includes several categories, each representing crucial aspect of IoT literacy.

Indicators: Within each category, specific indicators are outlined to help assess students' mastery of particular skills and knowledge.

Description: A concise description of each indicator clarifies the particular aspect of literacy being measured and the criteria for successful performance.

For instance, Table 2 below presents an example of a grid used to assess students' IoT literacy.

Table 2. Example of the assessment grid

Area of Evaluation	Assessment Categories	Indicators	Description
IoT	Technical Knowledge	Understanding IoT Principles	Assessment of the level of comprehension regarding fundamental IoT concepts
	Programming and Programming of Microcontrollers and Microprocessors for IoT	IoT Programming Skills	Assessment of the aptitude for developing IoT programs
	Data Analysis	Processing and Analysis of IoT Data	Evaluation of the capacity for analysing IoT-generated data
	Solution Design	Development of IoT Systems	Appraisal of the capability to devise IoT solutions
	Ethical Aspects	Grasping Ethical Issues in IoT	Evaluation of awareness regarding the ethical dimensions of IoT

The educational tool was developed based on a comprehensive literature review, empirical research, and other contributions to assess student literacy in IoT. Thus, it is a robust mechanism for meticulously evaluating students' literacy in IoT while enabling the planning of strategic educational initiatives to enhance students' competencies and knowledge.

3.2 Data analysis method

The data analysis conducted in this study covers two crucial dimensions: conceptual comprehension and the promotion of digital literacy skills.

The first phase of the analysis scrutinised the normality of the data distribution. For this purpose, the Shapiro-Wilk normality test was conducted, a tool designed to determine the extent to which the data conforms to a normal distribution [31].

The second phase involved assessing the homogeneity of data between groups, which was achieved by using the F-test [31], [32]. This stage is crucial for verifying the appropriateness of subsequent analysis and ensuring the accurate interpretation of findings.

The final phase involved hypothesis testing regarding the impact of IoT-integrated DEMs on enhancing digital literacy skills and students' conceptual understanding. The Wilcoxon test was used to compare mean values between two independent samples and identify statistically significant differences to accomplish these objectives [33]. This methodology gains enhanced significance in the context of longitudinal data analysis, allowing for the evaluation of interventions' (in this case, IoT-integrated DEMs) impact on variables' dynamics across different time points [33], [34].

4 RESULTS

Three sequential stages marked the progression of the analysis, with each one playing a crucial role in clarifying different aspects of the research objectives.

4.1 First phase: Checking the normality of data distribution

In the first phase, a crucial assessment was conducted to determine the normality of the data distribution. This preliminary step is significant in statistical processing as it determines whether the observed values follow a normal distribution. To this end, the Shapiro-Wilk normality test was employed to assess the data's adherence to the normal distribution.

The outcomes of the Shapiro-Wilk test yielded the subsequent p-values:

EG: p-value = 0.123

CG: p-value = 0.078

Following a significance threshold of 0.05, the hypothesis asserting the normality of data distribution for both groups cannot be rejected (refer to Table 3).

Table 3. Structure of the study

Group	p-Value	Normal Distribution
Experimental Group (EG)	0.123	Corresponds
Control Group (CG)	0.078	Corresponds

4.2 Second phase: The analysis of data homogeneity

Further, the second phase focused on assessing data homogeneity between groups by employing the F-test, which is crucial to ensuring the validity of subsequent analysis and result interpretation [32], [33].

[32], [33] comprehensively outline and evaluate various methodologies for testing data homogeneity, including the F-test, providing substantial guidance on the technique's application and interpretation within diverse research contexts.

This approach facilitated determining whether the groups showed comparable variances, a crucial consideration for further analysis. The standard deviations for the experimental and CGs were 11.54 and 12.28, respectively.

While analysing the between-group variance, an F-test yielded a value of 1.29. The next step was to compare this value with the critical value of 3.35 for a significance level of 0.05 with (2, 27) degrees of freedom. The results indicate that the F-test value does not exceed the critical value. Thus, there is no statistically significant difference in variance between the groups. This crucial observation supports the assumption of equality of variance and provides a foundation for a more robust comparison of intergroup differences in the study. This finding is important because homogeneous variance provides more accurate and interpretable results from statistical analyses.

This step ensured the reliability of the subsequent analysis. The results are presented in Table 4.

Table 4. F-test results

Group	Standard Deviation
Experimental	11.54
Control	12.28
F-test value	1.29

4.3 Third phase: Testing the impact of IoT-integrated DEMs on students' literacy skills and understanding

In the third phase, hypotheses investigating the impact of IoT-integrated DEMs on literacy skills and conceptual understanding underwent empirical validation. This phase allowed for the assessment of the effectiveness of IoT-integrated DEMs as an educational tool to improve students' knowledge and skills.

Based on the data from preceding phases that confirmed data normality and homogeneity of inter-group variances, the research utilized statistical methodologies to determine the statistical significance of differences between the experimental and CGs.

[11], [19], [35], [36] highlight the significant role of modern educational technologies, including IoT-integrated DEMs, in enhancing academic quality and developing students' competencies in this field.

Within the scope of the IoT, various aspects of literacy were examined, including technical knowledge, programming, data analysis, solution design, and ethical considerations. As part of this analysis, each of the above criteria was meticulously examined and explored to determine the influence of IoT-integrated DEMs on fostering relevant skills and knowledge among students. This approach facilitated a comprehensive assessment of the impact of integrating the educational tool on shaping new aspects of literacy among students.

4.4 The analysis of students' conceptual understanding

Four key indicators were identified in the first-mentioned data skills area, which are vital benchmarks for assessing students' skills. These indicators represent fundamental components of data analysis and encapsulate distinct facets of students' conceptual understanding and knowledge. To develop the indicators, the authors analysed the research, including the works of [37], [38], [39].

Indicators included data collection (A1): This indicator assesses students' ability to collect data systematically. It may include the ability to select appropriate data sources and to collect data using a variety of methods and tools.

Data interpretation (A2): This indicator assesses students' ability to analyse and make sense of the data collected. It involves interpreting values, identifying trends, and recognising patterns in the data.

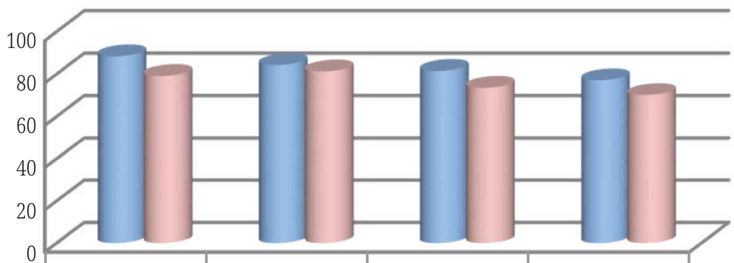
Data analysis (A3) assesses students' ability to analyse data more comprehensively by utilising a variety of statistical methods and tools.

Inference drawing based on data analysis (A4): This indicator assesses students' ability to formulate meaningful conclusions and recommendations based on the data analysed.

Each indicator marks a crucial point in the data processing and interpretation continuum, helping identify students' readiness in this domain.

The authors selected these four specific indicators because they embody an integrated approach to evaluating various aspects of the data management process. The selection of these indicators is justified by the aim of obtaining precise and dependable results when assessing students' level of competence. Each stage addresses vital steps in data analysis, from gathering information to drawing meaningful conclusions, offering an integrated perspective of their skills and knowledge in the subject area. This approach facilitates an accurate and comprehensive assessment of students' proficiency with data.

Data analysis skills were performed for the EG and CG; these results are presented in Figure 3.



	A1	A2	A3	A4
EG	88.35	84.24	81.48	77.04
CG	79.1	81.2	73.5	70.08

Fig. 3. Analysis of data skills

The outcomes analysis reveals that across all four categories (A1, A2, A3, A4), the EG achieved higher average scores than the CG. This observation suggests a potentially favourable impact of IoT-integrated DEMs on enhancing students' literacy skills within these categories.

The statistical examination yielded the following findings: The mean score in the EG was 82.3, compared to the CG's mean score of 76.75. The standard deviation within the EG was 5.59, compared to the CG's value of 5.17. The coefficient of variation for the EG was 6.79, whereas for the CG it was 6.72. When subjected to the Shapiro-Wilk test for normal distribution, the EG yielded a value of 0.045, while the CG produced a value of 0.072. The correlation coefficient between the groups was calculated to be –0.202. Further delving into the analysis revealed an F-value of 1.77 from the analysis of variance (ANOVA). Levene's test, used to examine the homogeneity of variances, yielded a value of 0.05. These findings highlight the differences between groups, emphasising the rigorous and robust statistical analysis needed to understand the effects of the factors under investigation. These statistical details are presented in Table 5.

Table 5. Statistical results on data skills

Statistical Data	Experimental Group (EG)	Control Group (CG)
Mean value (Mean)	82.3	76.75
Standard deviation (Standard Deviation):	5.59	5.17
Coefficient of Variation	6.79	6.72
Degree of normality of distribution (Shapiro-Wilk):	0.045	0.072
Correlation	–0.202	
Analysis of dispersion F (Analysis of Variance, ANOVA)	1.77	
Uniformity Tests (Leven's test)	0.05	

4.5 The analysis of students' IoT literacy

The Mathematics Education Standards emphasise literacy in mathematical modelling, which is applied in programming for the IoT [40], [41]. It is significant in developing technical skills, such as microcontroller programming. The ability to abstract real-world problems mathematically involves data analysis, which is essential for developing IoT-based solutions. Microcontroller programming and data analysis processes have become critical skills for the successful design and implementation of IoT projects. Thus, the development of students' mathematical literacy is directly related to their ability to effectively programme for IoT, perform technical data analysis, and develop innovative solutions based on this technology.

For the second phase of analysing IoT literacy, the authors decided to use a methodology that encompasses five crucial indicators to assess students' knowledge and skills more comprehensively and accurately. These methods were selected to assess technical skills, programming, data analysis, solution design, and ethical considerations in the IoT domain.

These indicators covered different areas, namely IoT technical skills (B1). This indicator is relevant for measuring students' overall technical understanding of IoT. Mastering the basics of technology and understanding its principles are fundamental to succeeding in this field.

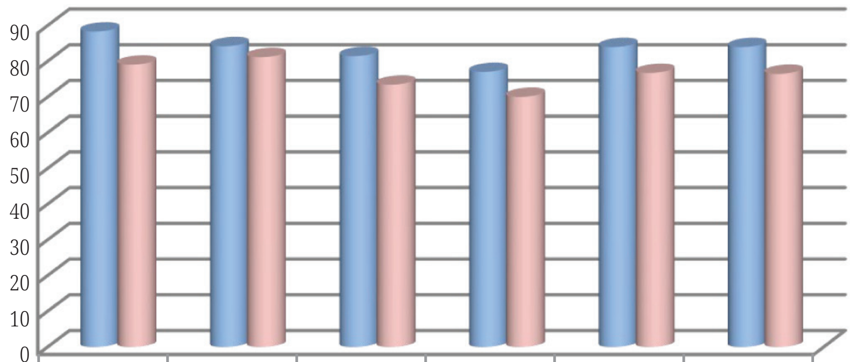
IoT Device Programming (B2): Programming plays a core role in developing and managing IoT devices. This indicator assesses students' ability to create programmes for the effective functioning of IoT devices.

Microcontroller and Microprocessor Programming for IoT (B3): The ability to programme microcontrollers and microprocessors is essential for IoT device development. This indicator focuses on the specific technical skills required to work with hardware in the IoT domain.

Data analysis from IoT devices (B4): The assessment of this indicator is significant for measuring students' ability to process and analyse data from IoT devices effectively. This skill is essential for extracting valuable information from the collected data.

Solution design based on IoT (B5): This indicator assesses students' ability to create practical and functional solutions using IoT concepts. It is an essential skill for successfully applying technology to real-world projects. The inclusion of this indicator underscores the significance of integrating ethical considerations into IoT technology development. It reflects the authors' awareness of the importance of ethics in developing and using new technologies.

Figure 4 visually presents the level of IoT literacy among students in this domain.



	B1	B2	B3	B4	B5	B6
EG	88.35	84.24	81.48	77.04	84.01	84.01
CG	79.1	81.2	73.5	70.08	76.77	76.52

Fig. 4. Level of IoT literacy among students

For example, the results of the technical skills (B1) analysis reveal that the EG exhibited an average skill level of 88.35, surpassing the level noted in the CG, where an average skill value of 79.1 was observed.

The EG results in indicator B2 (IoT Device Programming) are 3.04 points higher than the CG's, suggesting that students who took the experimental course may have a higher level of programming skills.

The results of the EG also outperformed those of the CG results in B3 by 7.98 points, indicating a deeper understanding of programming microcontrollers and microprocessors for IoT.

Regarding data analysis from IoT devices (B4), the EG demonstrates superiority by 6.96 points, which may indicate the effectiveness of the data analysis techniques implemented in the experimental group.

The scores in B5 confirm that the EG has a higher level of literacy in solution design based on IoT, outperforming the CG by 7.24 points.

The scores of the EG in B6 also indicate a greater awareness of ethical aspects in developing IoT solutions, surpassing the CG by 7.49 points.

This observation suggests a favourable impact of the proposed educational approach on enhancing students' technical capabilities. Concurrently, the dispersion of values and the coefficient of variation within the EG (12.27% and 13.88%, respectively) demonstrate a greater diversity in skill levels within this group.

Overall, the results of the EG, after applying the described methodologies to all indicators from B1 to B6, clearly demonstrate a high level of IoT literacy compared to the conventional group. These results confirm the effectiveness of the chosen assessment methods and provide significant data about learning success in this area.

The correlation analysis provides insight into the interrelationship between the groups, showing a moderately positive correlation (0.665). This correlation emphasises the consistency of technical proficiency among students in both groups. Furthermore, the analysis of variance (ANOVA) findings substantiate the presence of statistically significant differences between groups ($F = 20.5$), supporting the claims about the impact of the educational approach on technical skill levels.

The implications of these findings underscore the crucial role of rigorous statistical data analysis in assessing the effectiveness of learning and developing students' technical skills in IoT digital education. These statistical findings are presented in Table 6.

Table 6. Statistical results on technical skills

Statistical Data	Groups	B1
Mean value (Mean)	EG	88.35
	CG	79.1
Standard deviation (Standard Deviation)	EG	12.27
	CG	7.41
Coefficient Variations (Coefficient of Variation)	EG	13.88
	CG	9.38
Degree of normality of distribution (Shapiro-Wilk)	EG	0.073
	CG	0.021
Correlation	0.665	
Analysis variance F (Analysis of Variance, ANOVA)	20.5	

The remaining categories were also analysed using statistical methods to identify differences between the experimental and CGs. The findings are presented below.

Programming IoT Devices (B2): An analysis of mean scores between the EG ($X1 = 4.0$) and CG ($X2 = 3.5$) revealed a statistically significant difference ($t \approx 2.678$, $p < 0.05$). This finding indicates that students in the EG demonstrate an advanced level of literacy in programming IoT devices.

Programming Microcontrollers and Microprocessors for IoT (B3): The results of the t-test also show a statistically significant difference between the EG ($X1 = 3.9$) and the CG ($X2 = 3.3$) ($t \approx 2.291$, $p < 0.05$). This observation highlights that students in the EG demonstrate higher proficiency in programming microcontrollers and microprocessors for IoT.

Analysis of Data from IoT Devices (B4): The results of the t-test reveal a statistically significant difference between the EG ($X1 = 4.2$) and the CG ($X2 = 3.7$) ($t \approx 3.221$, $p < 0.05$). This implies that students in the EG demonstrate a higher proficiency in analysing data from IoT devices.

Designing Solutions Based on IoT (B5): An analysis of the t-test outcomes reveals a statistically significant difference between the EG ($X1 = 4.1$) and the CG ($X2 = 3.6$) ($t \approx 3.015$, $p < 0.05$). This indicates an increased level of literacy among students in the EG in understanding solutions based on IoT.

Ethical Considerations in IoT Solution Development (B6): The t-test results reveal a statistically significant difference between the EG ($X1 = 4.4$) and the CG ($X2 = 3.9$)

($t \approx 2.678$, $p < 0.05$). This finding highlights a higher level of literacy among students in the EG when considering ethical aspects in the development of IoT solutions.

Consequently, based on the t-test analysis of each category of IoT literacy, it is evident that students in the EG demonstrate a higher level of literacy across all assessed categories compared to the CG. This substantiates the efficacy of incorporating such an educational tool, i.e., DEMs, to cultivate IoT competencies.

5 DISCUSSION

Unlike other studies [25] and [32] that focus on a narrow range of skills, this research covers a wide range of IoT skills, including technical skills, programming, data analysis, developing innovative IoT solutions, and ethical considerations. It provides a deeper understanding of the impact of IoT integration in education.

The analysed data showed that students in the EG who worked with IoT-integrated DEMs demonstrated significantly higher comprehension and skill scores compared to the CG. It indicates the effectiveness of such materials in enhancing students' skills.

Students in the EG demonstrated a deeper understanding of data collection, interpretation, analysis, and drawing conclusions from data. It distinguishes this study from works that pay little attention to conceptual understanding [5], [12].

The study found significant improvements in IoT device programming skills, microcontroller and microprocessor design skills, and IoT device data analysis skills. It underscores the effectiveness of such educational tools in helping students acquire the practical skills essential for working in the IoT field.

The study highlights the critical role of IoT-integrated DEMs in developing students' ability to think innovatively and create IoT solutions. This is a crucial distinction from other studies that may place less emphasis on the creative aspect of IoT learning.

The meticulous analysis of the collected data has yielded invaluable insights into the efficacy of IoT-integrated DEMs, particularly in nurturing students' proficiency in the intricate landscape of IoT literacy. The subsequent findings provide a brief overview and lay the groundwork for a thorough discussion covering several crucial categories.

Analysing students' conceptual understanding is an integral part of assessing the success of the educational process in developing data skills. These analyses (A1, A2, A3, A4) measure students' skill levels and assess their comprehension of key concepts and ideas related to the data.

The data analysis of the skills in the experimental and CGs not only indicates higher scores in favour of the EG but also suggests that students in this group possess a more profound understanding of the concepts related to data collection (A1), data interpretation (A2), data analysis (A3), and drawing inferences based on data analysis (A4). Such conceptual understanding contributes to deeper and more sustainable learning, as well as the development of knowledge and skills.

IoT Technical Skills (B1): The initial observation regarding IoT technical skills (B1) is a crucial measure of the effectiveness of the educational tool. The significant improvement in this category highlights the educational tool's effectiveness in successfully introducing and reinforcing the fundamental concepts of the IoT to students. This noticeable improvement reflects a deeper understanding of the technical aspects of the IoT domain.

Programming IoT Devices (B2): The noticeable advancement in programming IoT devices (B2) is also a significant indicator of the success of the educational tool. The enhancement in this category indicates the effectiveness of DEMs in enhancing the practical skills required for programming IoT devices, thereby confirming the practical value of the educational tool in developing essential competencies for future IoT professionals.

Programming Microcontrollers and Microprocessors for IoT (B3): The categorization of B3 into programming microcontrollers and microprocessors for IoT signifies a more in-depth exploration of practical skills. The improvement in this category demonstrates the effectiveness of DEMs in preparing students to address more complex technical challenges associated with programming microcontrollers and microprocessors in the IoT domain.

Analysis of Data from IoT Devices (B4): It plays a vital role in developing and implementing IoT solutions. The enhancement in this category underscores the educational tool's crucial role in refining the analytical skills necessary for effectively interpreting and utilising the data influx from IoT devices. In other words, it substantiates the DEM's role in empowering students with essential analytical capabilities.

Innovative IoT Solution Design (B5): It is a critical competency in the IoT. The enhancement in this area highlights the effectiveness of DEMs in nurturing students' inherent ability to think systematically and create innovative solutions using IoT technologies. This aspect highlights the crucial role of the advanced educational tool in fostering this fundamental competency.

6 CONCLUSION

This study explored the impact of the IoT-integrated DEMs on students' comprehension of conceptual knowledge and acquisition of new skills. By exploring this research question, the study identified the potential benefits and challenges associated with the implementation of IoT-integrated DEMs in the educational domain. The presented research extensively explored students' literacy levels in the IoT domain using the educational tool IoT-integrated digital educational materials.

Overall, the study confirmed the importance of integrating IoT technologies into educational paradigms and the potential of IoT-integrated DEMs to enhance the quality of educational processes [8], [9], [10], [42]. The integration of IoT technologies and IoT-integrated DEMs promotes digital literacy by fostering critical thinking and enhancing students' comprehension of intricate concepts essential for real-world application [15], [16], [17].

The analysis showed a significant improvement in students' competencies in various categories of IoT, such as technical skills, programming proficiency, data analysis skills, solution ideation abilities, and ethical considerations. The statistical data from the study confirmed the significance of the observed differences between the experimental and CGs, strongly affirming the effectiveness of the educational tool.

Nonetheless, it is essential to acknowledge several significant limitations that should be considered when interpreting the results and applying the proposed methodologies.

Firstly, the limited sample size restricts the possibility of generalising the findings to a broader population of students. Since data were collected only from students at a specific higher education institution, their characteristics and needs may differ significantly from those at other educational institutions or regions.

Second, the proposed methodology for measuring IoT literacy may not be sufficient to assess the full range of IoT knowledge and skills, despite covering various categories. Additional categories such as pragmatic application, solving complex problems, or analysing real-world scenarios might also significantly help in understanding literacy levels. Nevertheless, it provides valuable and extensive data, which can be a useful tool for measuring and evaluating students' literacy in the IoT domain.

Lastly, IoT-integrated DEMs could vary depending on the context and characteristics of educational programs. Thus, the findings may be limited to the specific educational tool applied and proposed in this paper.

Despite these limitations, the research findings still provide valuable insights into the relationship between students' IoT literacy and the effectiveness of DEMs. Therefore, these findings might serve as a starting point for future research to improve the current methodology, take into account additional factors or challenges, and analyse a broader audience.

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