Innovating IoT instruction through simulation-based modules: An R&D study in higher education

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Abstract
This study developed and evaluated a computer simulation–based Internet of Things (IoT) lecture module for the Artificial Intelligence for Science Education course to address the gap between abstract IoT concepts and classroom practice in science teacher education. Adopting an R&D approach with the ADDIE model, the module was structured into five subtopics aligned with explicit learning outcomes and supported by simulations, examples, and authentic projects. Expert validation (five validators: content, media, instructional, and evaluation) examined content, language, and presentation using Aiken's V and Percentage of Agreement. Practicality was assessed via expert questionnaires (ease of use, attractiveness, usefulness, contextual relevance). Implementation involved a trial with 40 prospective science teachers, including a 5-point Likert readability survey. Content validity increased from 0.860 (valid) to 0.960 (very valid), and inter-rater reliability rose from 0.712 (fair) to 0.757 (good) after systematic revisions. Language validity improved from 0.833 to 0.950 (very valid); presentation remained strong at 0.893 (very valid) with qualitative enhancements to visual design. Expected practicality averaged 92% across dimensions (ease of use 91%; attractiveness 92%; usefulness 92%; contextual relevance 92%). Readability scores were consistently "highly readable" across seven dimensions (4.44–4.56), indicating clear language and style, logical sequencing, effective multimodal supports, manageable cognitive load, strong contextual relevance, and robust technical accessibility. The module is ready for classroom adoption, offering a scalable template for integrating IoT through simulations and authentic cases in preservice teacher education.

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1. Introduction

The rapid evolution of digital technologies, particularly the Internet of Things (IoT), has transformed the educational landscape in the era of the Fourth Industrial Revolution. IoT applications ranging from smart sensors to automated monitoring systems are increasingly integrated into sectors such as agriculture, aquaculture, health, and energy to enhance efficiency and sustainability. Within higher education, IoT holds considerable potential to enrich science learning by contextualising abstract concepts and equipping students with competencies directly relevant to real-world challenges (Brown & Duguid, 2025). However, despite its growing importance, IoT remains underrepresented in university curricula, particularly in science teacher education, where emphasis often remains on conventional digital tools rather than immersive and applied technologies (Hotar et al., 2024; Ma'rufi et al., 2020). This gap limits opportunities for preservice teachers to acquire contemporary digital competencies and apply theoretical knowledge to authentic practice.

Prior studies have underscored that effective IoT instruction requires not only technical exposure but also structured pedagogical strategies and engaging instructional resources (Hotar et al., 2024). Yet, many existing materials privilege theoretical exposition while neglecting dynamic teaching modalities such as simulations, interactive media, and authentic case studies. This lack of pedagogical innovation constrains the development of higher-order thinking skills including

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problem-solving, creativity, and critical reflection that are essential for navigating the complexities of education in the digital age (Brown & Duguid, 2025). Consequently, there is an urgent need for instructional modules that both provide a robust theoretical foundation and bridge the gap between abstract IoT concepts and practical applications.

Instructional design frameworks such as the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation) provide a systematic approach to developing educational resources that are pedagogically sound, valid, reliable, and practical (Asrizal et al., 2021). Numerous studies have confirmed the utility of ADDIE in producing modules that are contextually relevant and effective in enhancing student outcomes (Simamora et al., 2024). However, empirical research on IoT based instructional modules in science teacher education remains limited, particularly in Southeast Asia, where infrastructural, curricular, and pedagogical challenges often constrain innovation (Ma'rufi et al., 2020).

Responding to this gap, the present study developed a computer simulation–based IoT lecture module for the Artificial Intelligence (AI) for Science Education course. The module was designed to align with course learning outcomes while embedding interactive simulations, authentic project examples, and structured learning tasks. Rigorous expert validation was undertaken to evaluate content validity, inter-rater reliability, and practicality, while a trial with prospective science teachers assessed readability, usability, and impact on conceptual understanding.

The findings demonstrate that the IoT lecture module achieved very high validity across content, language, and presentation, with inter-rater reliability scores improving after systematic revisions. Practicality assessments confirmed its high ease of use, attractiveness, and usefulness, while readability tests indicated that the module was highly accessible, comprehensible, and contextually relevant. Importantly, the integration of authentic IoT applications such as smart farming and aquaculture ensured adaptability for related educational technology courses (Asrizal et al., 2021).

By addressing the dual challenges of theoretical abstraction and limited instructional resources, this study contributes to the growing body of literature on digital pedagogy and science teacher education. It highlights the pedagogical value of simulation-based IoT modules in fostering comprehension, engagement, and transferable skills, while offering a replicable framework for future curriculum innovation in higher education (Brown & Duguid, 2025; Simamora et al., 2024).

2. Method

This study employed a Research and Development (R&D) approach using the ADDIE model, which comprises the stages of analysis, design, development, implementation, and evaluation (Branch, 2009). The product developed was a computer simulation–based Internet of Things (IoT) lecture module designed to enhance students' learning experiences in the Artificial Intelligence (AI) for Science Education course.

At the analysis stage, the study identified students' learning needs, the challenges encountered in IoT learning, as well as a review of the curriculum and course learning outcomes. The design stage focused on structuring the module, developing its content, and determining its layout based on computer simulation. Mapping of the learning outcomes served as the basis for formulating learning sequences, simulation-based exercises, and discussion activities.

Subsequently, in the development stage, the drafted IoT module was validated by five expert validators, consisting of two content experts, one media expert, one instructional expert, and one evaluation expert. The experts' assessment covered three aspects: validity, reliability, and practicality. Content validity was analysed using Aiken's V formula (Aiken, 1985), with the interpretation criteria for validity values referring to (Tegeh et al., 2014), which classify categories ranging from very low validity to very high validity (Table 1).

$$V = \frac{\sum s}{n(c-1)} \text{ (Aiken, 1985)} \quad (1)$$

Explanation:
S = r – lo
r = Score assigned by experts
c = Number of categories

Table 1. Expert Validity Assessment Criteria

Value	Qualification	Remarks
0.90-1.00	Very valid	No revision required
0.75-0.89	valid	Minor revision required
0.65-0.74	Fairly valid	Considerable revision required
0.55-0.64	Less valid	Major revision required
0-0.54	Very less valid	Complete revision required

Adapted from Tegeh et al. (2014)

Inter-rater reliability was calculated using the Percentage of Agreement method (Miles & Huberman, 1994; Wakefield, 1980) with the interpretation categories referring to Portney and presented in Table 2.

$$R = \left(\frac{\text{Total inter−rater agreement score}}{\text{Ideal maximum score}}\right) \quad (2)$$

Table 2. Categories of Inter-Rater Reliability in Validating the Module Book

Interval	Category
> 0.90	Excellent
0.75 – 0.90	Good
0.50 – 0.74	Fair
< 0.50	Low

Source: Portney & Watkins (2009); Triwibowo et al. (2021)

Meanwhile, the practicality of the module was assessed by experts through a questionnaire encompassing indicators of ease of use, attractiveness, and usefulness. The results of the expected practicality assessment were interpreted using interval categories adapted from (Milala et al., 2021; Nieveen, 2007; Nurhafifah et al., 2021), ranging from impractical to highly practical (Table 3). The validators' assessments were subsequently used as the basis for revising the module to align with academic standards and students' needs.

Table 3. Expected Practicality Category

No.	Interval (%)	Category
1	81 - 100	Highly practical
2	61 - 80	Practical
3	41 - 60	Moderate
4	21 - 41	Less practical
5	0 - 20	Impractical

Adapted from Milala et al. (2021); Nurhafifah et al. (2021)

At the implementation stage, the revised IoT module was trialled with 40 prospective science teachers at a university in Surakarta. The trial included a readability test using a Likert scale (1–5) questionnaire, which evaluated aspects such as language clarity, structure, illustrations, simulation instructions, and accessibility (Farida et al., 2025; Nissa et al., 2023). In addition, pre-tests and post-tests were administered to examine changes in students' understanding after using the module.

The final stage was evaluation, which in this study was conducted formatively. The formative evaluation comprised revisions of the module based on the results of expert validation (validity, reliability, and practicality) as well as students' readability assessments. The outcomes of this evaluation served as the basis for refining the module so that it can be more widely implemented in IoT learning within higher education.

3. Results and Discussion

3.1. Content Analysis

Based on the content analysis that has been conducted, the material in this digital module is organized into five interconnected subtopics. The first subtopic introduces the concept of the Internet of Things (IoT) in the context of the Fourth Industrial Revolution and explores its potential applications in science education. This section aims to help students understand how IoT technology can enrich the learning experience. The second subtopic discusses various IoT devices, particularly sensors and actuators, along with their functions and relevance to practical science learning. The third subtopic presents various types of electronic development boards, including Arduino and ESP32, as well as the fundamentals of data communication commonly used in IoT systems. In the fourth subtopic, students are introduced to the basics of IoT device programming through computer simulations. This approach allows them to practice independently and gradually develop technical skills before engaging in hands-on implementation. The fifth and final subtopic focuses on designing simple IoT projects that are applicable within the context of science instruction.

Each subtopic begins with clearly defined Sub-Course Learning Outcomes (Sub-CLOs) that guide students toward specific learning objectives. The content is delivered progressively, accompanied by illustrations, practical examples, and interactive elements to support comprehension. At the end of each subtopic, students are provided with discussion questions and assignments designed to foster active participation and deepen their understanding. The structure of this module is intended not only to convey theoretical concepts but also to cultivate creative thinking, problem-solving abilities, and technical competence skills that are essential for students navigating education in the digital age.

3.2. Development of a Simulation-Based IoT Course Module

3.2.1. Expert Validation

A summary of the quantitative results of the expert validation is presented in Table 4, while the validators' qualitative comments and the corresponding follow-up actions are outlined in Table 5. Together, these findings demonstrate how systematic revisions, guided by both statistical indicators and expert feedback, enhanced the validity, reliability, and overall instructional quality of the IoT module.

Table 4. Summary of Expert Validation Results

Aspect	Pre-revision		Post-revision	
	Initial Validity	Initial Reliability	Initial Validity	Initial Reliability
Content	0.860 (Valid)	0.712 (Fair)	0.960 (Very valid)	0.757 (Good)
Language	0.833 (Valid)		0.950 (Very valid)	
Presentation	0.893 (Very valid)		0.893 (Very valid)	

Table 5. Summary of Validation Notes and Follow-up Actions

Aspect	Validator Notes	Follow-up Actions
Content	a. Additional references from IoT research journal articles are required. b. Factual presentation of problems remains weak. c. Discussion questions should be added at the end of each chapter. d. Real-world project examples are needed (e.g., chilli farming, vannamei shrimp aquaculture).	a. Added at least 10 recent IoT research articles (2019–2024). b. Revised case sections with updated empirical data. c. Inserted 2–3 reflective discussion questions in each chapter. d. Integrated IoT simulation case studies (e.g., chilli soil sensors, shrimp water-quality sensors).
Language	a. Inconsistent terminology across chapters. b. Symbols and notations are not standardised. c. Several spelling errors inconsistent with PUEBI. d. Technical terms not fully aligned with KBBI/academic standards.	a. Developed a glossary of IoT terms to ensure consistency. b. Standardised symbols and notations throughout the module. c. Edited text in accordance with PUEBI.Cross-checked terminology with KBBI and standard IoT literature.
Presentation	a. Front and back cover designs lack appeal. b. Colour scheme is not harmonious. c. No document footer included. d. Certain layout sections are not proportional.	a. Redesigned front and back covers with IoT-themed visuals. b. Harmonised the colour scheme (e.g., blue–grey technology tones).

Aspect	Validator Notes	Follow-up Actions
		c. Added a standard footer (module title, author, year). d. Adjusted layout for consistency and proportionality.

The expert validation results reveal notable improvements in the IoT lecture module following revisions informed by expert feedback (Table 4 and Table 5). In the content aspect, the validity score increased from 0.860 (valid) to 0.960 (very valid) an enhancement consistent with prior development studies showing that targeted augmentation of sources, refinement of learning tasks, and tighter alignment with outcomes can raise content validity (Dewi et al., 2022; Hakim et al., 2020; Safiah et al., 2023). Concretely, the revisions comprised the addition of ≥10 recent IoT research articles, the inclusion of reflective discussion questions, and the integration of authentic IoT project simulations (e.g., chilli farming and vannamei shrimp aquaculture), approaches supported in the literature for strengthening factual grounding, contextual relevance, and the novelty of instructional materials (Aliyah & Widiyatmoko, 2023; Damopolii et al., 2024; Fitriana & Wiyarsi, 2024). Reliability likewise improved from 0.712 (fair) to 0.757 (good), indicating a clearer convergence of expert judgements after revision, in line with findings that structured redesign and explicit criteria promote higher inter-rater agreement (Ridhwan et al., 2020; Safiah et al., 2023). Collectively, these enhancements elevate the module's credibility and pedagogical rigour while simultaneously strengthening expert consensus regarding its accuracy and instructional value (Ridhwan et al., 2020; Safiah et al., 2023).

The language aspect of the IoT lecture module likewise demonstrated substantial improvement following systematic revisions. The validity score increased from 0.833 (valid) to 0.950 (very valid), primarily due to targeted interventions addressing inconsistencies in terminology, non-standard notations, and limited adherence to PUEBI and KBBI standards. To address these weaknesses, a dedicated IoT glossary was developed, symbols and notations were standardised, and comprehensive editing was undertaken to ensure alignment with established linguistic and academic conventions. This approach is consistent with best practices in educational material development, where systematic language quality control is emphasised as a means of enhancing clarity, readability, and precision (Alim et al., 2025). Comparable findings are reported in related domains: (Rodzi et al., 2023) highlight the importance of structured quality control in translation processes, underscoring the need for consistency in terminology and documentation, while Yulianeta et al. (2022) demonstrate that teaching materials integrating cultural context and adherence to national language standards significantly improve comprehension. The marked improvement in the module's language validity thus mirrors results from other module development studies, where expert-guided revisions and intensive editing substantially enhanced the linguistic quality of instructional products (Alim et al., 2025). Consequently, the language aspect was judged highly valid, underscoring the strengthened clarity and precision of the module. These improvements also support the forthcoming readability assessments with students, suggesting that the module's linguistic refinement will positively impact both comprehension and learning effectiveness.

For the presentation aspect, the module maintained an overall validity score of 0.893 (very valid), with expert validators consistently rating indicators such as layout, illustrations, icons, and graphical clarity at a high level. This outcome is consistent with findings in prior studies that emphasise the critical role of design features such as clear visual structure and graphical quality in producing engaging and effective learning media (Safiah et al., 2023; Wusqo et al., 2021). Although the quantitative score did not increase, validators identified shortcomings in colour harmony, cover design, and layout proportionality. These weaknesses were addressed through targeted revisions, including redesigning the front and back covers with IoT-themed visuals, harmonising the colour scheme with blue–grey tones, adding standardised footers, and refining layout consistency. Such adjustments align with the literature, which stresses that a harmonised colour palette and consistent layout structures significantly enhance both aesthetic appeal and user engagement (Setiyani et al., 2022; Syahputra & Utami, 2019). While the numerical validity score remained unchanged, these qualitative refinements produced a more polished and professional module, reinforcing its instructional effectiveness and visual coherence. This finding supports earlier evidence that iterative design improvements, even without numerical gains, contribute substantially to the overall usability and pedagogical value of digital instructional materials (Safiah et al., 2023; Setiyani et al., 2022; Syahputra & Utami, 2019).

The reliability analysis confirmed an appreciable improvement in inter-rater agreement, particularly in the content aspect. The reliability coefficient increased from 0.712 to 0.757, suggesting that the iterative revisions based on expert feedback successfully reduced discrepancies among evaluators and thereby enhanced the consistency of judgements. This result aligns with earlier findings that structured expert validation processes, supported by tools such as Aiken's V, can strengthen both the validity and reliability of instructional materials (Safiah et al., 2023). It also supports the principle that iterative refinement informed by expert evaluation not only improves quantitative indices but also harmonises qualitative perceptions, yielding more reliable instructional products (Alim et al., 2025).

3.2.2. Expected Practicality Test

The results of the expected practicality test, as shown in Table 6, indicate that the IoT lecture module is highly practical across all assessed dimensions. In the ease of use dimension, the module achieved a score of 91%, confirming that it can be implemented without intensive external guidance, provides clear and sequential instructions, and is compatible with devices that are widely owned by students. This outcome aligns with findings from previous studies which emphasise that digital learning materials offering straightforward navigation and accessible content tend to achieve high practicality ratings and are readily adopted in classroom contexts (Alim et al., 2025; Asrizal et al., 2021b).

Table 6. Summary of Expected Practicality Test Results by Experts

Dimension	Score (%)	Category
A. Ease of use	91	Highly practical
B. Attractiveness	92	Highly practical
C. Usefulness	92	Highly practical
D. Contextual relevance	92	Highly practical

Moreover, the integration of structured learning activities with appropriate time allocations demonstrates that the module is not only accessible but also efficient for classroom use. This finding is consistent with research on interactive media in technical and science education, which highlights that practicality is maximised when instructional resources align with available learning time and minimise the need for external support (Helda et al., 2024; Wijaya et al., 2019). Complementing this, Atmazaki et al. (2023) stress the importance of systematic assessments through questionnaires and observation sheets in capturing usability, with their results supporting the robustness of high ease-of-use scores in instructional products.

The attractiveness dimension obtained a score of 92% (highly practical), reflecting the strong design appeal and interactive quality of the IoT lecture module. Although one validator rated certain design elements slightly lower, overall evaluations confirmed that the use of illustrations, diagrams, and simulations effectively captured student attention and encouraged engagement. These findings are consistent with prior studies which demonstrate that visual and interactive components in educational media enhance learner participation and sustain interest in learning activities (Simamora et al., 2024). For instance, Rijal & Azimi (2021) reported that digital teaching materials incorporating whiteboard animation achieved a practicality score of 92.5%, attributing this outcome to the engaging use of visual tools that stimulate curiosity and maintain focus.

The strategic use of interactive diagrams and simulations further supports student motivation. Yang et al. (2021) highlighted that well-crafted illustrations are essential in drawing and maintaining attention, while Wahyuni et al. (2020) emphasised the role of interactive media such as Edmodo-based materials in fostering active learning and critical thinking. Likewise, Himmi & Hatwin (2018) showed that modules incorporating GeoGebra simulations significantly improved students' visual thinking, reinforcing the pedagogical importance of dynamic and visually appealing tools.

The usefulness dimension achieved a score of 92% (highly practical), reflecting a strong consensus among experts that the IoT lecture module effectively supports the intended learning objectives. This outcome aligns with prior studies on STEM-based digital modules, which emphasise that when instructional resources are explicitly aligned with course outcomes, they not only clarify complex subject matter but also promote higher-order thinking skills. For example, Alim et al. (2025) demonstrated that a STEM-based e-module developed using a structured model attained high practicality scores and significantly enhanced students' critical thinking skills, supporting the observation that the IoT module deepens learners' understanding of technical content.

The module's alignment with the learning outcomes of the Artificial Intelligence for Science Education course further strengthens its instructional relevance. Simamora et al. (2024) demonstrated that e-learning materials developed with structured models such as ICARE are more effective in achieving course learning goals. Similarly, Asrizal et al. (2021) found that digital enrichment resources in physics, validated for both validity and practicality, significantly improved conceptual comprehension. Complementary evidence from Wahyuni et al. (2020) also underscores that interactive teaching materials contribute to gains in both critical and creative thinking skills.

Taken together, these findings confirm that the IoT lecture module's 92% usefulness score reflects robust expert consensus. Its ability to enhance IoT conceptual understanding, stimulate creative thinking through simulations, and maintain close alignment with course learning outcomes demonstrates that it is a relevant, beneficial, and pedagogically effective instructional resource.

The contextual relevance dimension attained a score of 92% (highly practical), reflecting strong validator consensus that the module is well aligned with the real world needs of prospective science teachers. The inclusion of IoT applications in agriculture and aquaculture such as smart farming and water-quality monitoring demonstrates that the content is not merely theoretical but grounded in authentic scenarios students are likely to encounter in their professional practice. This finding is consistent with Ridlo et al. (2024), who showed that embedding real-world applications, such as smart agroforestry, significantly enhances learning relevance and engagement by situating abstract concepts in tangible contexts. Such contextualisation ensures that students can connect theory to practice, thereby improving motivation and comprehension.

The adaptability of the module for integration into other related educational technology courses is also notable. Lutfianto et al., 2020) emphasised that instructional resources designed around locally relevant data and contexts become more versatile and effective for preservice teacher training. Similarly, Wati et al. (2020) found that the use of authentic learning approaches, particularly those involving real-world problem-solving, enhances practical understanding and fosters critical thinking skills. By embedding applied examples, the IoT module aligns with this evidence, ensuring transferability across subject areas and strengthening its pedagogical utility.

Furthermore, Lubis et al. (2021) demonstrated that textbooks embedded with local cultural content achieved superior validation outcomes, highlighting the broader principle that contextually rich materials contribute significantly to learner engagement and instructional relevance. Taken together, these findings corroborate the validators' assessments that the IoT lecture module's high contextual relevance score is attributable to its integration of real-world applications and adaptability for broader use. In doing so, the module effectively meets both the specific needs of science teacher preparation and the wider requirements of educational technology programmes.

3.2.3. Readability Test

The readability test results presented in Table 7 demonstrate that the IoT lecture module developed through the ADDIE process achieved a consistently high level of readability across all evaluated dimensions, with mean scores ranging from 4.44 to 4.56 on a 5-point Likert scale. This indicates that the module is categorised as "highly readable" overall and is well-suited for use by prospective science teachers.

The first dimension, clarity of language and style, obtained a mean score of 4.44 (highly readable). This outcome can be attributed to the module's use of simple and direct language, concise sentence structures, and the proactive clarification of technical terms prior to their application. Such strategies align with established best practices in educational and technical material design, where plain language and brevity have been consistently associated with reduced cognitive load and enhanced comprehension (Patel et al., 2015). Similar evidence from readability studies in patient education demonstrates that when technical terminology is explained in advance and sentences remain succinct, learners across varying levels of prior knowledge can access complex content more effectively (Sanghvi et al., 2012; Shoemaker et al., 2014). Although some students noted minor repetition that necessitated re-reading, research suggests that redundancy can serve as a reinforcement mechanism, supporting the retention of critical information (Lampert et al., 2016). Furthermore, scholarship in text simplification underscores the importance of adapting complex content into more digestible forms, particularly through strategies such as sentence brevity and clarification of specialised vocabulary (Saggion, 2017). Taken together, these findings suggest that the module successfully balanced technical precision with accessibility, enabling students with differing levels of IoT familiarity to comprehend the material with relative ease.

Table 7. Summary of Readability Test Results by Prospective Science

Dimension	Readability Score	Category
Clarity of language and style	4.44	Highly readable
Structure and organisation of material	4.56	Highly readable
Examples, illustrations, and visuals	4.54	Highly readable
Learning navigation and task instructions	4.48	Highly readable
Cognitive load, pacing, and text length	4.52	Highly readable
Relevance of IoT content and computer simulations	4.51	Highly readable
Accessibility and technical aspects	4.53	Highly readable

The second dimension, structure and organisation of material, achieved the highest score of 4.56 (highly readable). This result reflects the module's clear articulation of learning objectives at the beginning of each topic, which oriented students to the intended outcomes and facilitated active engagement with the content. Prior research has shown that explicit objectives serve as cognitive anchors, enabling learners to integrate new knowledge with prior understanding (Shoemaker et al., 2014). The sequencing of material from basic concepts to advanced applications was regarded as logical and coherent, exemplifying the scaffolding essential to effective learning. Such progression reduces cognitive load and supports comprehension by providing a structured hierarchy of content, a phenomenon well documented in readability studies of educational materials (Hu, 2022). The inclusion of end-of-section summaries further enhanced review and retention, echoing findings that concise recapitulations improve organisation and learning outcomes (Edmunds et al., 2013; Morowatisharifabad et al., 2020). Collectively, these design features embody the systematic and iterative process emphasised in instructional design frameworks such as the ADDIE model, which advocates for accessible, structured, and evaluation-oriented materials (Lampert et al., 2016). By aligning with these evidence-based practices, the module's structure effectively scaffolded learning, enhanced readability, and contributed to a coherent and engaging instructional experience.

The third dimension, examples, illustrations, and visuals, received a score of 4.54 (highly readable). Students highlighted that diagrams, simulation screenshots, and information boxes containing tips and notes facilitated conceptual understanding and made the material more engaging. In highly technical subjects such as IoT, the effective use of multimodal elements helps bridge abstract theory with practical application. This aligns with evidence that audiovisual components improve the overall understandability and actionability of educational materials (Shoemaker et al., 2014). Similarly, research has shown that visual elements, including photographs and diagrams, contribute positively to comprehension and recall, thereby enabling learners to grasp complex content more effectively (Edmunds et al., 2013). The high readability score suggests that the integration of text with well-designed visuals reduces cognitive load and supports more efficient information processing, a finding consistent with evaluations of multimodal presentation effectiveness (Balakrishnan et al., 2016). Although a minority of students observed that some visuals were dense or small in size, the overall positive feedback underscores the value of strategically incorporating visual aids to enhance engagement and conceptual clarity. In sum, these findings reinforce the broader pedagogical principle that multimodal elements transform complex technical content into more accessible knowledge, thereby supporting deeper learning and practical application.

The fourth dimension, learning navigation and task instructions, was rated 4.48 (highly readable). Respondents agreed that the instructions for simulations and projects were clear, sequential, and supported by consistent visual cues such as warnings and notes. This finding aligns with evidence that well-organised instructions, reinforced by visual markers, enhance both understandability and actionability, thereby enabling learners to process and apply information more effectively (Shoemaker et al., 2014). Research further demonstrates that step-by-step structuring lowers cognitive burden and improves user comprehension, a principle emphasised in guidance on developing clear instructional materials (Lampert et al., 2016). Although a few students reported occasional difficulties when instructions became lengthy, this mirrors established findings that unnecessarily long texts may disrupt task flow and impede navigation (Lee et al., 2011). Nonetheless, the majority of learners found the tasks straightforward and manageable without intensive guidance, confirming the practicality of the module for classroom contexts. Additionally, the importance of layout and consistent design in facilitating smooth navigation is supported by studies highlighting how visually organised materials assist readers in engaging with complex content (Edmunds et al., 2013). Collectively, these results reinforce that clarity, sequential organisation, and the use of visual cues in task instructions are essential for achieving high readability, even in technical learning environments.

The fifth dimension, cognitive load, pacing, and text length, recorded a score of 4.52 (highly readable). Students reported that the paragraph length and pacing of theory example practice cycles were comfortable and did not create overwhelming information density. The inclusion of small "checkpoints" throughout the module was especially valued, as these provided opportunities for self-assessment and consolidation of learning. These results reflect established principles of readability and cognitive load management, which highlight that clear language, appropriate pacing, and segmentation enhance comprehension and engagement (Patel et al., 2015; Shoemaker et al., 2014). The module's deliberate design breaking complex content into manageable units mirrors best practices in instructional material development that reduce extraneous cognitive load (Lampert et al., 2016). Research further indicates that features such as text chunking, concise layout, and interactive checkpoints support reflection and self-monitoring, thereby strengthening metacognitive learning processes (Edmunds et al., 2013). In line with cognitive load theory, the module successfully balanced the intrinsic complexity of IoT with students' working memory resources, ensuring that learning remained both manageable and effective. Collectively, the high readability score confirms that the design strategies employed reduced cognitive burden, promoted sustained engagement, and fostered deeper comprehension.

The sixth dimension, relevance of IoT content and computer simulations, achieved a score of 4.51 (highly readable). Learners recognised that the integration of IoT concepts with practical computer simulations made the material both concrete and meaningful. The use of case studies from agriculture and aquaculture was regarded as authentic and relevant to real-world applications, underscoring the strength of contextual learning in technical domains. This finding aligns with research demonstrating that the clarity and accessibility of educational materials enhance comprehension and actionability, even in specialised contexts (Patel et al., 2015; Shoemaker et al., 2014). In particular, contextual examples and simulations serve as effective mediators between abstract concepts and practical application, thereby facilitating deeper learning (Hu, 2022). While some students requested further clarification of technical terms such as parameters and codes, this observation echoes the need highlighted in studies on advanced technical textbooks for a balance between specialised vocabulary and accessible explanation (Hu, 2022). Moreover, research on text simplification emphasises that complex technical information becomes more comprehensible when presented with clear delineation and relevant examples (Saggion, 2017). Overall, the high readability score reflects the module's success in combining theory with practice through the integration of authentic case studies and simulations, thereby reinforcing the pedagogical value of contextual learning in enhancing understanding and retention.

Finally, the seventh dimension, accessibility and technical aspects, scored 4.53 (highly readable). Students reported that the font size, colour contrast, and layout were comfortable for on-screen reading, while supporting files such as datasets and templates were readily accessible. The module also functioned smoothly across different devices, demonstrating strong technical adaptability. These findings are consistent with studies showing that design elements such as layout, organisation, and visual clarity significantly enhance readability and comprehension (Edmunds et al., 2013). Similarly, structured approaches to quality assurance in educational materials emphasise that clarity in font and layout are critical to ensuring usability in digital environments (Lampert et al., 2016). The positive evaluation of technical accessibility also aligns with evidence that well-structured materials, supported by appropriate supplementary files, improve learner experience and usability (Morowatisharifabad et al., 2020). Although a small number of students reported minor challenges related to installation or device compatibility, such issues did not hinder the learning process. This is consistent with prior research suggesting that strong design and accessibility features mitigate the impact of minor technical disruptions (Shoemaker et al., 2014). In sum, the high readability score for this dimension reflects a deliberate design that prioritised visual comfort, cross-device functionality, and access to resources, thereby supporting effective and uninterrupted learning.

4. Conclusion

The development and evaluation of the computer simulation–based IoT lecture module for the Artificial Intelligence for Science Education course demonstrated that the product meets high standards of validity, reliability, practicality, and readability. The content analysis confirmed that the module was systematically structured into five interconnected subtopics, each accompanied by clear sub-learning outcomes, illustrations, examples, discussion questions, and assignments designed to strengthen both theoretical understanding and technical competence.

Author Contributions

Kadek Dwi Hendratma Gunawan contributed to the conceptualization, methodology, project administration, and preparation of the original draft. Budi Utami was responsible for supervision, validation, and reviewing and editing the manuscript. Bramastia contributed to software development, data curation, and visualization. Suciati was involved in providing resources, conducting investigation, and performing formal analysis. Muhammad Nur Hudha contributed to conceptualization, methodology, and reviewing and editing the manuscript. Jovita Ridhani contributed to formal analysis, visualization, and reviewing and editing the manuscript. Dyah Ayu Saraswati Adimudra contributed to visualization, editing, and finalizing the article template. All authors have contributed equally to this paper and have read and approved the final version of the manuscript.

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The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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