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Development of digital handouts based on critical thinking skills as teaching material for pre-service science teachers

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ABSTRACT

Critical thinking is crucial for future science teachers to succeed in their roles. Not only does it prepare them for future challenges, but it also helps them guide students in developing these essential skills. It is crucial to develop learning materials integrated critical thinking skills aspects for pre-service science teachers (PSSTs). This research seeks to design and assess web-based digital handouts intended to enhance critical thinking skills. Utilizing both qualitative and quantitative methods as research methodology to evaluate the validity of the handouts and explore PSSTs' perceptions of the digital handouts. The Technology Acceptance Model (TAM) was used to analyze PSSTs' perceptions regarding the acceptance and use of digital handouts. The digital handouts were validated by two experts and tested by fifty two PSSTs at a university in Riau, Indonesia. The results showed an average rating of 89.1% in the 'very good' category, indicating that the digital handouts were perceived as useful, easy to use, and highly adoptable in learning activities. Furthermore, the findings align with previous studies that highlight the positive PSSTs' perceptions regarding the implementation of digital handout in learning.

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INTRODUCTION

Critical thinking is a crucial competency for students to thrive in the challenges of the 21st century (Sellars et al., 2018). However, developing essential 21st-century skills is rarely addressed in higher education settings (Marangio et al., 2024; Marquis et al., 2017). Studies indicate that critical thinking skill in university graduates do not develop automatically (Janssen et al., 2019). This skill is seldom taught in a direct manner, and its development largely depends on the effectiveness of the instruction. For pre-service science teachers (PSSTs), it is essential to create learning opportunities that help them reflect on their own beliefs and values related to critical thinking, while also enabling them to incorporate these skills into the lessons they plan—highlighting the fundamental role of critical thinking in scientific learning. As a 21st-century competency, critical thinking skill comprise several essential components, including effective reasoning (which involves the application of both inductive and deductive reasoning), systematic thinking, making well-informed judgments and decisions, and problem-solving (Lorencová et al., 2019; Partnership for 21st Century Skills, 2015). These fundamental aspects are purposefully embedded within the learning stages to enhance the critical thinking abilities of PSSTs.

PSSTs, in particular, require strong analytical and problem-solving abilities to effectively engage with scientific concepts, evaluate evidence, and foster inquiry-based learning in their future classrooms. However, traditional instructional methods often fail to sufficiently develop these skills, as they tend to emphasize rote memorization over higher-order cognitive processes. Previous research has highlighted insufficient critical thinking abilities among PSSTs. For example, Trostek (2020) carried out a study in Sweden using essays, revealing deficiencies in PSSTs' analytical and reasoning abilities. Similarly, a study identified a gap in the progression of pre-service teachers' critical thinking skills and underlined the necessity of focused and efficient interventions to reinforce these crucial proficiencies (Fitriani et al., 2019).

Additionally, an initial observation conducted by researchers at a public university in Riau, Indonesia, revealed that low participation in learning was a major factor contributing to the lack of critical thinking capacity among PSSTs. Many PSSTs were less engaged with the learning materials provided by educators, which hindered their ability to develop analytical and reasoning skills. One potential solution to address this issue is the use of handouts in classroom instruction. Chang, Lin, and Lu (2021) found that implementing handouts in lectures significantly increased student engagement, as they provided structured guidance and helped students navigate learning more effectively. Moreover, handouts facilitated classroom participation, making students more involved in discussions and active learning activities. Similarly, Chacon and Janssen (2021) emphasized that handouts was served as a fundamental resource, providing essential background information that acts as a foundation for critical thinking development. By incorporating well-designed handouts, teachers can make the classroom more participatory that enhances student engagement and supports the cultivation of critical thinking skills among PSSTs.

Handouts can be presented digitally through a website with learning tools, such as handout options to download and print, and interactive quizzes to practice can increase the attractiveness of handouts for students. Technology in education acts as a tool to create a lively, concrete, and exciting learning process (Astuti et al., 2020; Mahapatra, 2015). Web-based technologies are widely adopted in digital education because they offer user-friendly access to learning content across devices and are relatively cost-effective to implement in various educational settings.

Educational websites can be designed to help students grasp specific learning content while also supporting the development of their knowledge, abilities, and overall competencies (Bolkan et al., 2016). As a form of online instructional media, web-based learning platforms are designed with educational objectives in mind, and many educational institutions have utilized them to integrate science content into comprehensive digital learning resources (Astuti et al., 2020; Wang et al., 2017). Digitalization of teaching materials is not spared in efforts to raise the quality of the teaching and learning activities. Non-print learning resources in the form of handouts containing learning materials can be packaged through the website. Besides enhancing the flexibility of learning, the

integration of technology into educational activities can also foster the growth of students' critical thinking skills and competencies (Lorencová et al., 2019).

Research conducted by Alhefnawi (2021) found that online handouts provide students with additional knowledge, enhancing their understanding of course material. Similarly, Khotimah and Hastuti (2021) reported that students who had access to digital handouts as instructional materials demonstrated better cognitive learning outcomes, improved critical thinking skills, and enhanced science process skills compared to those who did not utilize handouts. To maximize their effectiveness, digital handouts should be designed with engaging content, incorporating visually appealing components such as colors and images attract students and facilitate the learning process (Nerita et al., 2017).

While in science education, prior research has examined the overall advantages of digital handouts and the importance of instructional materials in fostering competence in critical thinking, few have specifically focused on the integration of systematically designed, web-based digital handouts aimed at developing critical thinking skills among PSSTs. This study offers a unique contribution by combining pedagogical design with digital innovation through the development of interactive, visually engaging handouts that align with critical thinking components. Therefore, this study makes a distinct contribution by integrating instructional design with critical thinking pedagogy and evaluating technology acceptance.

Based on the background presented, there is a clear need to develop digital handouts to support PSSTs in enhancing their critical thinking skills. These digital handouts will be designed to present learning materials systematically, in a visually appealing format, and structured to stimulate students' analytical thinking. Additionally, the integration of technology within these handouts will improve accessibility and flexibility for both lecturers and students, further enhancing their effectiveness and usability.
This study aims to develop web-based digital handouts specifically designed to foster critical thinking skills among PSSTs. Furthermore, to assess user perceptions, this research will employ the Technology Acceptance Model (TAM). The study will involve the design and production of digital handouts that seamlessly integrate critical thinking elements, ensuring they serve as an effective instructional tool in teacher education.

OBJECTIVES OF THE STUDY

The purposes of this research are to develop digital handouts designed to enhance the critical thinking skills of PSSTs and to explore their perceptions of the digital handouts. The research is guided by the following specific aims:

1. To explain the process of developing digital handouts grounded in critical thinking skill frameworks.
2. To examine PSSTs' perception of the digital handouts in terms of perceived usefulness, ease of use, and behavioral intention.

MATERIALS AND METHODS

Research Design

This research utilized a mixed methodology research design to develop digital handouts based on critical thinking skills and assess the PSSTs' perception regarding digital handouts.

Participants

The research was conducted in a public university located in Indonesia. The participants who involved in this study consist of:

1. A science education expert was involved in validating the content of the digital handouts, ensuring alignment with pedagogical goals. Additionally, an expert in educational technology assessed the quality and suitability of the handouts as instructional materials in a digital learning environment.
2. The study involved 52 PSSTs enrolled in the *Fundamentals of Mathematics and Science Education* course. Participation was voluntary. These PSSTs used the digital handouts during the course, and their perceptions were collected to evaluate how the materials supported the promotion of critical thinking skills.

Research Instruments

Two research instruments were used to collect data consisting of:

1. Two evaluative forms to examine the validity of digital handouts. Validation by subject matter expert assessed the suitability of the digital handout content with learning outcomes, the accuracy of the digital handout content, the application of the digital handout content, and the suitability of the digital handout content in supporting critical thinking skills. Meanwhile, validation by teaching material expert assessed the relevance, accuracy, user interface, grammatical suitability, and readability of the digital handout. The expert validation sheet employs a 4-point Likert scale, spanning from "Strongly Disagree" to "Strongly Agree". The validators also provided criticisms and recommendations regarding improvements to the digital handout.
2. The researchers used the TAM questionnaire to examine the PSSTs ' perception regarding digital handouts. The questionnaire used in this study was adaptated from Davis, Bargozzi, & Warshaw (1989). Item reliability of the TAM questionnaire (0.83) were above 0.67 or good category (Yusuf et al., 2024). The questionnaire employed a 4-Likert scale, spanning from "Strongly Disagree" to "Strongly Agree" to measure three aspects, which include Perceived Usefulness (PU), Perceived Ease of Use (PEU), and Behavioural Intention to Use (BI) of PSSTs.

Data Collection Procedure

There were three stages carried out in this study, namely 1) development of digital handouts, 2) validation of digital handouts by experts, and 3) digital handouts trial by PSSTs to determine their perceptions. The initial phase involved the development of digital handouts, starting with a comprehensive analysis stage. This stage included: (1) Content analysis, which involved selecting material aligned with the course outcomes for PSSTs education; (2) User analysis, to assess students' readiness and ability to engage with new technology integrated into instructional materials; (3) Software requirement analysis, identifying suitable platforms and tools for designing the digital handout website; and (4) Hardware requirement analysis, ensuring that students' devices—such as computers or smartphones—were compatible for accessing and using the digital handouts effectively.

Need analysis was the first step to start developing digital handouts. The need to develop the PSSTs' critical thinking skills became the foundation for the development of these digital handouts. In the digital handouts developed, the material was compiled based on the Fundamentals of Mathematics and Sciences Education course syllabus. The sub-course outcomes that became the learning objectives to be achieved were limited to the topics on the Nature of Mathematics and Sciences Learning, Science Learning Methods and Approaches, and Science Process Skills. These topics were chosen because the learning materials stimulate PSSTs to think critically. The curriculum investigation process found that the learning objectives which PSSTs must achieve included: 1) The PSSTs can understand the nature and principles of science learning, 2) The PSSTs can explain methods and approaches in science learning, and 3) The PSSTs can understand process skills in science education.

The next phase was the design stage, which comprised several key components: (1) the design of instructional content; (2) the development of a flowchart outlining the sequence and structure of the digital handout creation process aimed at enhancing critical thinking skills; and (3) the creation of a storyboard, which provided a visual representation of the handout's flow based on the flowchart, serving as a guide for the subsequent development stage. Subsequently, the development of digital handout was carried out using Google Sites, a website-building platform provided by Google. Google Sites provides a secure virtual learning space where

students can access materials easily and engage with the content at their own pace, promoting independent learning and autonomy (Culajara, 2022). Google Sites can be utilized as a platform for developing instructional media that integrates various teaching materials—including images, graphics, simulations, and videos—which collectively support the enhancement of learners' critical thinking skills (Pradana et al., 2024; Susanti et al., 2023). Digital handouts which is developed using Google Sites can be accessed using computer or smartphone through a browser with an internet connection. Furthermore, the digital handouts were validated by subject matter expert and teaching material expert. At this stage, the content of learning materials in digital handouts is developed too. In addition, the interface of the digital handouts is also developed based on the storyboard at the design stage.

The second stage was validation of the digital handouts by the experts. From the validation results, the level of eligibility and recommendations for improving digital handouts from experts were obtained.

The third stage was identifying PSSTs ' perceptions of digital handouts after using the digital handouts during 3 weeks of the course. PSSTs who accessed digital handouts were asked to complete a questionnaire on their perception of digital handouts using the basic TAM Questionnaire through Google Form.

Data Analysis

This research utilized both quantitative and qualitative data analysis techniques to comprehensively investigate the development of digital handouts and the perceptions of PSSTs regarding their use, based on the Technology Acceptance Model (TAM). The Qualitative data were obtained from expert validators' comments and recommendations, which were then analyzed to improve the digital handouts. Meanwhile, quantitative data were collected from validation assessment which completed by experts and analyzed using descriptive statistics to assess the eligibility of the digital handouts. The results of the validation score calculation were categorized based on the following criteria (Yoda et al., 2024).

Table 1. Category Interval Utilizing a 4 Point Likert Scale

Interval Score	Category
$X \geq 3.25$	Highly Valid
$2.5 > X \geq 3.25$	Moderately Valid
$1.75 > X \geq 2.5$	Fairly Valid
$X < 1.75$	Not Valid

Quantitative data were collected through questionnaires administered to PSSTs and analyzed using descriptive statistical techniques. This method allowed for the summarization of responses across nine questionnaire items, providing insights into students' perceptions of using digital handouts in the learning process. The descriptive statistics offered a clear overview of key aspects such as perceived usefulness, perceived ease of use, and behavioral intention toward using digital handouts. The findings from this analysis served as a basic principle for developing practical recommendations to improve the quality of digital handouts as teaching material.

Ethical Considerations

This study followed fundamental ethical guidelines, emphasizing voluntary involvement and the protection of participants' information. Informed consent was obtained after participants were clearly briefed on the study's objectives and potential implications, ensuring their full understanding before involvement.

RESULTS AND DISCUSSION

Characteristics of Digital Handouts to Train Critical Thinking

Digital handouts to improve critical thinking skills contain three main features: Material description, extension problems, and competency tests. Based on the characteristics of handouts, the learning materials presented are essential materials on predetermined topics. Digital handouts also integrate components of critical thinking skills, especially in the extension problems feature in which stimulates PSSTs to practice the skills of composing reasons effectively (related to applying various inductive and deductive reasoning), using systematic thinking, making judgments and decisions, and solving problems. The skills integrated into the digital handouts are aspects of critical thinking (Partnership for 21st Century Skills, 2015). For example, science learning in the 21st century faces significant challenges, especially in integrating technology, improving critical thinking skills, and preparing students for global challenges. In the digital handouts, research articles related to the role of science teachers in learning are presented. PSSTs are stimulated to analyze the fundamental roles of science teachers to prepare students for the 21st century. PSSTs analyze empirical evidence and evaluate based on information from scientific articles presented in digital handouts. PSSTs are also given learning materials supported by diagrams to facilitate understanding concepts. An example of the digital handout interface is shown in Figure 1.

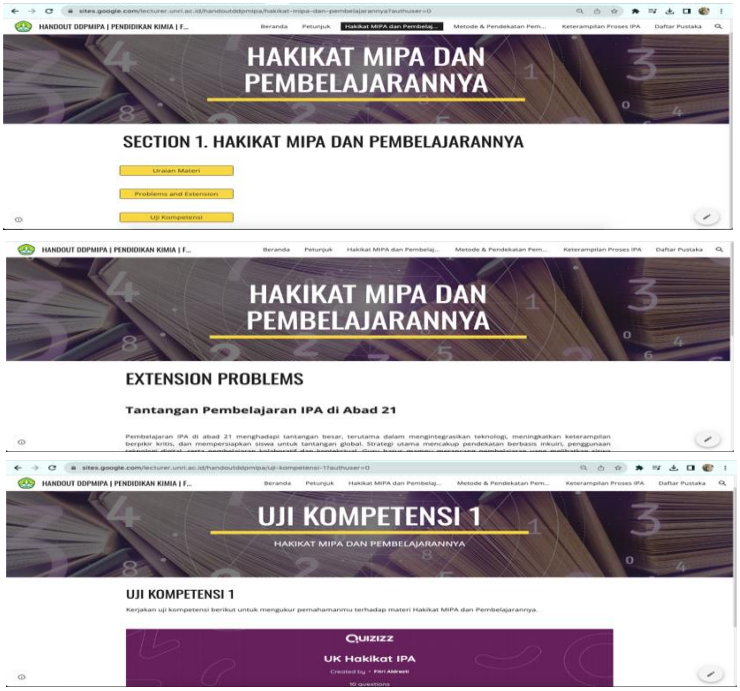

Fig. 1. The Interface of Digital Handouts

Experts' Judgement Validation

The results of validation on developing digital handouts based on critical thinking skills for PSSTs are presented, as well as validators' recommendations . Digital handouts will be applied to PSSTs to promote critical thinking skill. However, the content of digital handouts should undergo thorough evaluation, with the assessment of content validity relying on expert judgment to ensure accuracy, relevance, and alignment with educational objectives. The results of the validators' assessment and recommendations for revising the digital handouts product are described as follows.

1. Subject Matter Expert Judgements

The digital handouts was developed as teaching materials which the topics consist of: 1) the Nature of Mathematic and Science Learning, 2) Science Learning Methods and Approaches, and 3) Science Process Skills. The aspects assessed include suitability of the content with learning outcomes, accuracy of the content, currency of the content, and suitability of the content in supporting critical thinking skills. The average score for subject matter expert validation is shown in the Table 2. Furthermore, from the validation process that has been carried out, the recommendations given by the material expert validators are showed in Table 3.

Table 2. Subject Matter Expert Validation Results

Aspects	Average Validation Score	Criteria
Suitability of content with learning outcomes	3,67	Highly Valid
Accuracy of the content	3,75	Highly Valid
Currency of content	3,50	Highly Valid
Suitability of the material in supporting critical thinking skills	3,50	Highly Valid
Average Score	3,60	Highly Valid

Table 3. Subject Matter Expert Recommendations

Aspects	Subject Matter Expert Recommendations
Suitability of content with learning outcomes	• In the test feature, students should be able to determine which questions still need to be answered correctly.
Accuracy of the content	• Give problems that are logical or based on the facts of current science learning. • Add diagrams related to the concepts presented.
Currency of content	• Present material with up-to-date references (e.g. on the 21st century science teacher paradigm). • Provide explanations or descriptions for the illustrations presented.

From the validation process, the subject matter expert suggested adding diagrams to the digital handouts to make it easier for PSSTs to understand the information presented. However, multimedia is used sparingly. Presenting the same information, both audio and visual, can cause redundancy effects and increase the cognitive load in teaching materials for PSSTs. The additional cognitive load caused by overwhelming visual stimuli and a demanding learning environment can be considered as "learning-irrelevant" factors (Skulmowski & Xu, 2022). Consequently, the integration of multimedia in digital handouts should be selective and purposeful, ensuring that visual elements complement rather than duplicate textual information. Furthermore, subject matter experts also suggested to provide opportunities for PSSTs to find out questions that need to be answered correctly in the competency test section. This feedback was a reflection for students to improve their understanding of concepts and critical thinking skills (Karaoglan Yilmaz & Yilmaz, 2020; Yilmaz & Yilmaz, 2020). This approach enabling students to evaluate their own understanding and pinpoint areas requiring further review.

2. Teaching Material Expert Judgements

Relevance, accuracy, user interface, suitability of grammar, and readability aspects were assessed by teaching material expert validator. The average score of the teaching materials expert validation is shown in Table 4. In addition, from the validation process that has been carried out, the recommendations given by the material expert validators are showed in Table 5.

Table 4. Teaching Material Expert Validation

Aspects	Average Validation Score	Criteria
Relevance	3,8	Highly Valid
Accuracy	3,50	Highly Valid
User Interface	3,50	Highly Valid
Grammatical Appropriateness	3,67	Highly Valid
Readability	3,67	Highly Valid
Average Score	3,63	Highly Valid

Table 5. Teaching Material Expert Recommendations

Aspects	Material Expert Recommendations
Relevance	• Show the competencies related to critical thinking aspects that pre-service science teachers need to achieve.
User Interface	• Please provide 'Back to Homepage' button • A hyperlink goes to the wrong page on the topic of 'Science Learning Methods and Approaches'.

One crucial recommendation by teaching material experts was to present the learning outcomes which related to critical thinking skills. Learning activities must be aligned with the learning objectives set. According to Hammond and Brown (2021), learning outcomes statements clearly communicate to students what they are expected to achieve upon successful completion of the learning process. For lecturers, they serve as a guide in selecting suitable instructional methods and assessment strategies to help students attain those outcomes (Hammond & Brown, 2021). Therefore, critical thinking competency should be displayed on digital handouts as a skill to be achieved by PSSTs.

Furthermore, the navigation system in digital teaching materials is urgent because it affects users' ease of access to digital handouts later. Therefore, improvements were made to the buttons used in digital handouts.

Pre-Service Science Teachers' Perception

Digital handouts were tested with PSSTs to determine their impressions of the teaching materials. Fifty-two PSSTs were accessed the handouts. The PSSTs' perceptions regarding digital handouts are shown in Table 6.

Table 6. TAM Perception of Pre-Service Science Teacher

Aspects	**Percentage of Perception Score**	**Criteria**
Perceived Usefulness (PU)	90,74%	Very Good
Perceived Ease of Use (PEU)	89,06%	Very Good
Behavioural Intention to use (BI)	87,50%	Very Good
Average Percentage	89,10%	Very Good

The findings in Table 6 demonstrate that PSSTs have a very positive perception of digital handouts designed to enhance critical thinking skills. The Technology Acceptance Model (TAM) questionnaire was used to evaluate their internal beliefs, attitudes, and intentions regarding digital handouts in learning (Yusuf et al., 2024). Three fundamental aspects—PU, PEU, and BI—were assessed, with all aspects receiving "Very Good" ratings.

The high Perceived Usefulness (PU) score (90.74%) suggests that PSSTs strongly believe that digital handouts enhance their learning performance, aligning with the idea that perceived usefulness is a key fundamental factor influencing technology acceptance in education (Sukendro et al., 2020). The structured and interactive nature of digital handouts provides clear explanations, well-organized content, and embedded assessments, which may

contribute to their high perceived usefulness. Moreover, the accessibility and flexibility of digital handouts allow students to interact with learning materials at their own track and convenience, further reinforcing their value in academic settings.

One of the statements in the PU aspect, "I would find digital handouts useful in my learning process," reflects this perception, indicating that PSSTs recognize the benefits of digital handouts in facilitating understanding, organizing information, and improving study efficiency. The present findings align with previous studies that emphasize the beneficial effects of digital educational resources on students' engagement and learning outcomes. For example, Thongkoo, Daungcharone, & Thanyaphongphat (2020) found that digital learning promoted positive perception toward learning system. Their study suggests that integrating new digital instructional tools fosters a dynamic and stimulating learning environment, which aligns with the results of this study.

The strong Perceived Ease of Use (PEU) score (89.06%) indicates that digital handouts were perceived as intuitive and user-friendly, making them accessible and easy to navigate for PSSTs. This ease of use lowers the barrier to adoption, potentially encouraging wider implementation in science education. However, despite the positive perception, support mechanisms are necessary to help PSSTs fully leverage digital tools in their future classrooms, ensuring that they are not only able to use digital handouts but also integrate them effectively into their teaching strategies.

A statement in the PEU aspect, "Learning to operate digital handouts would be easy for me," reflects this perception, suggesting that PSSTs find the interface and functionality of digital handouts straightforward and manageable. The perceived ease of use of a technology directly affects its acceptability and sustained utilization, as articulated in the Technology acceptability Model (TAM) (Davis et al., 1989). A well-designed digital handout should be structured logically, with clear navigation, responsive interactions, and minimal technical complexity to ensure a smooth learning experience.

Furthermore, the very good rating in Behavioral Intention (BI) scores indicates that PSSTs perceive digital handouts as an effective instructional tool. Within the BI indicator, PSSTs assigned a high score to the statement, "I presently intend to use digital handouts regularly during learning activities." This means that they recognize the value of digital handouts and are highly motivated to incorporate them into their learning process and future teaching practices. A high BI score implies that PSSTs are likely to adopt and integrate digital handouts into their instructional methods, further reinforcing the importance of embedding such tools into teacher training curricula.

Regarding perceived usefulness, several PSSTs highlighted how the structured flow and integration of visuals helped clarify complex scientific content. One participant shared, *"The handouts helped me connect the learning materials more easily, especially with the visuals and summaries at the end of each section."* Another stated, *"I liked how the handouts were accessible anytime, so I could go back and review the content before class or exams."* These reflections suggest that usefulness was not only associated with the information presented but also with how it was designed and delivered.

With regard to perceived ease of use, some of respondents commented on the intuitive and user-friendly interface. For example, one participant remarked, *"I didn't need much guidance; it was easy to follow and everything was clearly labeled."* While the other mentioned, *"I could easily find the topics I wanted to study, and the buttons worked well even on my smartphone."* These comments reinforce the idea that a low barrier to entry is essential for digital tools to be adopted in educational settings.

As for behavioral intention to use, participants expressed enthusiasm about continuing to use digital handouts in the times to come. One stated, *"I plan to utilize this kind of resource when I become a teacher—I think it's more engaging for students."* Another noted, *"I feel motivated to keep using digital handouts because it's less stressful."* These responses illustrate a strong intent to adopt and integrate digital handouts in future teaching practices, highlighting their potential as a sustainable instructional innovation.

These findings are consistent with prior research on technology acceptance, which emphasizes that a strong intention to adopt digital resources often leads to sustained use and effective integration into classroom practices (Songkram & Osuwan, 2022). According to Songkram and Osuwan (2022), when learners perceive digital learning platforms as both beneficial and user-friendly, they tend to develop favorable attitudes toward their use in educational settings. In a similar vein, Narayanan & Shankar (2021) found that complementing lectures with illustrated handouts significantly improved knowledge retention. Their participants reported that the visual elements in the handouts enhanced comprehension and supported their learning process by simplifying complex concepts. The present study supports these conclusions, as PSSTs expressed positive responses to the digital handouts, particularly appreciating the organized content, engaging visuals, and embedded assessment tools. These results indicate that incorporating digital handouts into instructional design can effectively promote long-term retention of scientific knowledge.

Given these insights, the strong TAM score in this study highlights the beneficial of digital handouts as an effective instructional resource for PSSTs. Future research could explore how different design elements and interactive features influence students' perceived usefulness over time, ensuring that digital handouts continue to evolve as an engaging and impactful learning resource.

However, while the results are largely in agreement with previous research, it is important to note that the efficacy of digital handouts is contingent upon various aspects. First, the design and quality of content are crucial factors in ensuring that digital learninng reasources effectively support learning objectives (Aldresti et al., 2023). Well-structured materials with clear explanations, relevant illustrations, and interactive elements can enhance comprehension and engagement, while poorly designed handouts may lead to cognitive overload and reduced learning efficiency. Second, the level of digital literacy among PSSTs influences their ability to navigate and utilize digital handouts effectively. PSSTs with limited experience in using digital tools may require additional training to fully benefit from these resources. Third, the integration of digital handouts into instructional practices must be carefully planned to align with pedagogical strategies. Simply providing digital materials without proper guidance or alignment with lesson objectives may not yield optimal learning outcomes. Finally, external factors such as technological infrastructure, accessibility, and students' motivation also contribute to the overall effectiveness of digital handouts. Therefore, while the positive reception of digital handouts in this study suggests their potential as valuable instructional tools, further research is needed to explore how these factors interact and influence learning outcomes.

CONCLUSION AND RECOMMENDATION

Conclusion

This study successfully developed and tested digital handouts designed to promote PSSTs' critical thinking skills. The Digital handouts' development process followed a structured approach, beginning with the analysis stage, followed by the design and development stages, ensuring that the digital handouts were pedagogically sound and technologically feasible. The inclusion of illustrative material descriptions, logical problems, and competency tests provided an interactive and engaging learning experience that enhanced critical thinking skills.

The validation process by experts confirmed validity of the digital handouts. Additionally, PSSTs' perceptions were evaluated using the Technology Acceptance Model (TAM), with results indicating a very positive perception. The perceived usefulness of the digital handouts was rated 90.74%, perceived ease of use 89.06%, and behavioral intention to use 87.5%, with an overall average rating of 89.1% in the "very good" category. These findings suggest that the digital handouts are both effective and user-friendly, encouraging their adoption in science education. The high perception scores across all three TAM aspects confirm that usefulness, simplicity of use, and intention to use are pivotal in technology adoption within educational contexts. The strong usability and intuitive navigation system of the digital handouts further support their successful implementation. This study presents

empirical evidence that well-structured digital handouts can effectively enhance students' positive perceptions of learning resource use.

Recommendation

Based on the findings, several recommendations can be made for the future adoption of digital handouts for teaching and learning activities:

1. Digital handouts should be systematically integrated into teacher education curricula to equip future educators with technological pedagogical skills. This will encourage PSSTs to adopt and utilize digital learning materials effectively.
2. Future versions of digital handouts should explore more interactive features, such as embedded simulations, adaptive learning pathways, and real-time feedback mechanisms. These enhancements can further improve engagement and learning outcomes.
3. Despite the high perceived ease of use, training programs should be provided to maximize the effectiveness of digital handouts. Educators should receive guidance on how to integrate digital handouts into lesson plans and facilitate critical thinking-based discussions using digital materials.

By addressing these recommendations, digital handouts can be further optimized and expanded, ensuring sustainable adoption and impactful learning experiences in science education.

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