DIGITAL LITERACY COMPETENCE OF PRE-SERVICE PHYSICS TEACHERS : A MIXED-METHODS ANALYSIS USING DIGCOMP 2.2

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ABSTRACT

Digital literacy has become a key competence for pre-service teachers in the current era of educational digital transformation, particularly in data-driven and simulation-based disciplines such as physics. This study analyzes the digital literacy competence of pre-service physics teachers using the DigComp 2.2 framework through an exploratory mixed-methods approach. Forty students from one physics education program participated, and an adapted 22-item DigComp instrument (Cronbach's $\alpha = 0.91$) was employed to measure five areas of competence. Quantitative findings indicate an imbalance in competence development. Digital Content Creation achieved the highest score (M = 4.08; 81.6%), reflecting strong technical–operational skills. In contrast, Information and Data Evaluation (M = 3.65; 73%) and Digital Safety (M = 3.48; 69.6%) were the weakest domains, indicating limited critical and protective digital abilities. Qualitative analysis further revealed difficulties in fact-checking scientific information and low awareness of personal data security. These findings provide empirical evidence of uneven digital skill development among pre-service physics teachers and highlight the need for targeted curriculum interventions that strengthen critical and protective digital competencies while reducing task-oriented approaches to digital use.

Keywords : *Digital Literacy, DigComp 2.2, Pre-Service Physics Teachers, Information Evaluation, Digital Safety, Mixed-Methods.*

INTRODUCTION

Digital transformation has significantly reshaped the landscape of physics education over the past decade. This transformation has altered how teachers access, process, and utilize digital resources to support physics learning. Within STEM classrooms, teachers are expected to integrate virtual simulations, data-driven analysis tools, sensor-based experimental devices, virtual laboratories, and even AR and VR technologies to facilitate inquiry-oriented learning experiences (Sumarni and Verawati, 2020; Hasanah et al., 2025; Mukti and Zulkarnain, 2025). These developments mark a shift from traditional procedural instruction toward learning models that emphasize data literacy, scientific modeling, and reasoning in digital environments, as noted by Lumbantoruan et al. (2025). In this evolving context, digital literacy becomes a multidimensional competence that is not limited to technical proficiency but also involves critical, ethical, and scientific decision making.

The integration of increasingly sophisticated digital tools in physics learning environments creates new demands on pre-service teachers. Unlike general digital content, digital resources used in physics education, such as simulation outputs, computational models, motion tracking data, and automated experimental datasets, involve epistemic risks. Their visual accuracy can make them appear reliable even when they contain conceptual errors if the data are not critically evaluated. Because of this, digital literacy for future physics teachers requires the ability to evaluate the credibility, accuracy, and scientific validity of digital information. This need is especially critical in physics because scientific errors derived from unverified digital data can easily lead to misconceptions that may persist in subsequent learning.

Studies across East and Southeast Asia highlight similar patterns. Research has shown that pre-service teachers in the region generally possess strong operational abilities but struggle with deeper dimensions of digital literacy, particularly in evaluating source credibility, detecting bias, and verifying the scientific accuracy of online material (Oktiningrum, 2025; Hanh, Huyen, and Linh, 2025). Cheng et al. (2020) also confirm that digital natives tend to master practical and application-oriented skills more rapidly than reflective and critical ones. These trends pose serious concerns for STEM education, where misinterpretation of scientific digital content can directly impede conceptual understanding.

In Indonesia, research on digital literacy is increasing but often focuses on basic technological use, learning platforms, or media creation. Sari et al. (2022) state that many studies emphasize operational competencies rather than scientific information evaluation, data literacy, or digital safety. These areas are essential for physics education because teachers must regularly interact with digital data, verify simulation accuracy, and ensure the secure use of laboratory management systems. The limited focus on these competencies indicates that the current understanding of digital literacy within Indonesian higher education is not yet aligned with the demands of modern physics learning environments.

A structured and comprehensive framework is therefore needed to evaluate and develop digital competencies among pre-service physics teachers. The European Digital Competence Framework (DigComp 2.2) is one of the most widely recognized international references for assessing digital literacy through five key domains, namely Information and Data Literacy, Communication and Collaboration, Digital Content Creation, Safety, and Problem Solving (European Commission, 2018; Carretero et al., 2022). The evolution of digital literacy frameworks, beginning from Gilster's foundational definition in 1997 to the multidimensional

DigComp model, reflects the growing global need for digital competencies that include critical and ethical components rather than solely technical ones.

Although DigComp 2.2 provides a robust framework, its direct application in physics teacher education remains limited. The framework does not specifically address disciplinary practices such as evaluating virtual laboratory data, interpreting simulation-based results, or managing digital laboratory identities. As a result, general digital literacy assessments may overlook critical competencies required for scientific accuracy in physics. This gap shows that a contextual adaptation of DigComp indicators is necessary for physics education in order to capture both operational and epistemic aspects of digital competence.

The present study responds to this research gap by adapting several DigComp 2.2 indicators to reflect the demands of physics education, including digital experimental data evaluation and simulation accuracy verification. Additionally, the study adopts an exploratory mixed-methods approach following Habibullah (2025), allowing both quantitative mapping of competence levels and qualitative exploration of the factors underlying observed disparities. This methodology enables a more comprehensive understanding of why operational skills develop more rapidly compared to critical and protective competencies.

Through this approach, the study aims to provide a detailed and contextually relevant analysis of digital literacy among pre-service physics teachers in Indonesia. The findings are expected to contribute to the development of digital literacy curricula that are aligned with the scientific, ethical, and technological realities of physics education. This alignment is essential for preparing future teachers who can responsibly navigate digital environments, safeguard scientific integrity, and utilize technology effectively in modern physics classrooms.

METHOD

Research Design

This study employed a sequential explanatory mixed-methods design, beginning with quantitative data collection and analysis to map the digital literacy profile, followed by qualitative analysis to explain emergent patterns. This design offers a comprehensive structural and phenomenological understanding of competence.

Adaptation of DigComp 2.2 Instrument for Physics Education (New Section)

A total of six DigComp indicators were modified to align with physics learning contexts. Examples include:

Original DigComp 2.2 Indicator	Adaptation for Physics Education
Evaluating data and information	Evaluating digital experimental data from virtual laboratories
Creating digital content	Producing simple physics simulations using Algodoo/PhET
Managing digital identity	Managing LMS accounts containing practicum records

The adaptation process was validated through expert judgment involving two digital-physics lecturers and one curriculum specialist.

Participants and Sampling Procedures

A total of 40 students from a physics education program participated. The sample consisted of 27 active students and 13 from previous cohorts. A Mann–Whitney U test revealed no

significant difference between cohorts (p = 0.362), allowing data to be pooled. As an exploratory study, generalizability is limited.

Instrument

The instrument comprised 22 Likert-scale items (1–5) adapted from DigComp 2.2 to reflect physics education contexts.

1. Instrument Adaptation: Items were contextualized for physics education (e.g., replacing "searching general information" with "searching and evaluating credibility of physics simulation data").
2. Content Validity: Judged by three experts (Physics Education, Educational Technology, Digital Literacy); all items had CVR > 0.78.
3. Construct Validity and Reliability: Item-total correlations ranged from r = 0.41–0.78; reliability was excellent (Cronbach's α = 0.91).
4. Example Item: "I regularly use two-factor authentication (2FA) and unique passwords for important academic and personal accounts."
5. Limitations: Self-report bias and absence of EFA/CFA warrant cautious interpretation.

RESULTS AND DISCUSSIONS

Result

1. Descriptive Statistics

Table 1. Digital Literacy Scores by DigComp Area (N = 40)

Competence Area	Mean	SD	%age	Category
Digital Content Creation	4.08	0.46	81.6%	Very High
Communication & Collaboration	3.92	0.51	78.3%	High
Digital Problem Solving	3.72	0.50	74.4%	High
Information & Data Literacy	3.65	0.48	73.0%	High
Digital Safety	3.48	0.62	69.6%	Moderate

The key finding is the substantial gap between Content Creation (81.6%) and Digital Safety (69.6%), indicating an imbalance between operational and protective skills.

2. Mann–Whitney U Test

No significant cohort differences were found (p = 0.362).

3. Qualitative Findings

Table 2. Thematic Analysis and Links to Quantitative Data

Theme	Description	Link to Quantitative Results
Task-Driven Usage	Technology used mainly for assignments.	Explains high operational skills.
Limited Fact-Checking	Difficulty verifying scientific sources.	Supports lower scores in Information Literacy.
Low Data Security Awareness	Reuse of passwords, privacy neglect.	Aligns with lowest Digital Safety score.
Dependence on Popular Apps	Reliance on Canva/Google Suite over scientific apps.	Explains strong content creation but weak scientific depth.
Need for Project-Based Training	Students request authentic case-based learning.	Basis for curriculum enhancement.

Discussions

The findings of this study reveal a clear imbalance in the development of digital competence among pre-service physics teachers, reflecting a broader pattern commonly observed in digital-native populations across Southeast Asia. Although participants demonstrated strong operational proficiency, particularly in tasks involving media production and digital collaboration, their critical and protective digital skills lagged significantly behind. This imbalance suggests that digital competence in physics teacher education continues to evolve unevenly, shaped more by habitual patterns of technology use than by systematic curriculum design or disciplinary needs. To provide a comprehensive interpretation, the discussion is organized around three major themes: the gap between operational and critical competence, specific weaknesses in information evaluation and digital safety, and structural factors influencing students' digital behaviors. Additional sections highlight the implications for physics education, the scholarly contribution of this work, and curriculum recommendations aligned with the empirical results.

Participants demonstrated their highest competence in Digital Content Creation (81.6 %) and Communication and Collaboration (78.3 %). These results align with the general tendency of digital natives to develop operational and creative skills independently through frequent engagement with social media platforms, multimedia tools, and collaborative digital environments (Carretero et al., 2022). The interview data reinforce this finding. Students frequently mentioned that applications such as Canva, Google Workspace, YouTube Edu, and other widely available tools were used intuitively and efficiently, often without direct instruction from lecturers. One participant explained, "For making posters or videos, I'm very used to it," highlighting the deep familiarity students have with task-oriented digital practices (Interview, M5).

However, the nature of this competence appears largely procedural. Students excel at producing visually appealing content or completing digital tasks, but this does not necessarily translate into epistemic digital literacy. As Themes 1 (Task-Oriented Usage) and 4 (Dependence on Popular Apps) demonstrate, digital activities are typically carried out to fulfill assignments quickly rather than to critically evaluate or construct scientific meaning. This distinction is crucial because in physics education, digital content creation requires more than aesthetic quality; it also demands conceptual accuracy, ethical representation of scientific information, and adequate validation of data sources.

The procedural orientation of students' digital activities mirrors patterns identified globally, where operational proficiency develops more rapidly than reflective and critical capacities (Cheng et al., 2020). The present findings suggest that while pre-service teachers have the technical ability to manipulate digital tools, they have not yet internalized the deeper principles governing scientific communication, accuracy, and epistemic responsibility.

Contrasting sharply with their strong operational skills, students' lowest performance occurred in Information and Data Evaluation (73 %) and Digital Safety (69.6 %). The low score for information evaluation is particularly concerning given the centrality of data interpretation and evidence validation in physics. Many students lack exposure to critical evaluation strategies such as lateral reading (Wineburg & McGrew, 2017), which limits their ability to assess the accuracy and reliability of scientific sources. This gap was evident in interview responses. One participant stated, "If the experimental data automatically comes from the simulation, I assume it must be correct" (Interview, M2). Such statements indicate a fundamental misunderstanding about the nature of scientific simulations, which often require cross-validation and conceptual interpretation.

Digital safety emerged as the weakest domain, revealing that many students lack basic protective behaviors such as password management, privacy settings, and risk evaluation. Theme 3 (Low Data Security Awareness) shows that several participants used identical passwords across multiple platforms, a practice that poses risks to both personal and institutional data. One student admitted, "I use the same password to make it easier… it's too complicated if they are all different" (Interview, M9). Studies by Sanjaya et al. (2024) and Almutairi et al. (2023) similarly highlight that digital safety remains underdeveloped among university students globally, suggesting that this issue reflects a systemic gap rather than an individual limitation.

In the context of physics education, weaknesses in information evaluation and digital safety carry additional disciplinary implications. Physics teachers must be capable of validating data from virtual experiments, recognizing limitations of digital simulations, and ensuring the secure use of laboratory management systems. Inadequate competence in these areas threatens both scientific integrity and the safe operation of digital environments that students will later manage in real classrooms.

The imbalance in digital competence is further shaped by structural factors that influence how pre-service teachers engage with technology. First, the culture of assignment-driven learning contributes to superficial digital engagement. Students use technology primarily when required for coursework and tend to prioritize speed and convenience over critical evaluation or exploration of alternative tools. This results in a shallow form of digital competence that is functional but not reflective.

Second, the limited use of advanced digital tools in lecturer-led instruction restricts students' opportunities to develop discipline-specific competencies. Puspitasari (2024) notes that students' digital proficiency is strongly influenced by lecturer practices; the present findings confirm this, as many students reported feeling more confident only when instructors provided step-by-step examples of technology use. Without consistent modeling from lecturers, students struggle to independently choose or evaluate digital tools for scientific purposes.

Third, students exhibit a preference for popular applications that are easy to use, such as Canva or Google Suite, rather than tools that would deepen their scientific understanding, such as sensor-based data acquisition systems, Python-based analysis, or physics simulation frameworks. While convenient, this preference reinforces operational rather than epistemic development, limiting students' readiness to engage with technology-rich physics pedagogy.

Together, these structural factors create an environment where digital competence develops in uneven ways, favoring operational fluency while neglecting critical evaluation, scientific verification, and digital protection.

The observed imbalance in digital competence has direct implications for the preparation of future physics teachers. Physics increasingly depends on accurate data interpretation, computational modeling, and simulation-based reasoning. Weak information evaluation skills may lead teachers to rely on unverified digital content, propagate misconceptions, or misinterpret simulation outcomes. Similarly, insufficient digital safety competence compromises not only personal data security but also the integrity of classroom learning platforms and student identities.

Given that physics teachers act as mediators of scientific knowledge, these weaknesses carry both pedagogical and ethical consequences. Teachers must be able to guide students in evaluating digital evidence, conducting safe online experiments, and distinguishing between scientifically valid and misleading sources. Without strengthening these competencies, the quality of physics learning in digital contexts may be reduced.

This study makes a notable methodological and conceptual contribution by adapting the DigComp 2.2 framework specifically for physics education. Previous research has largely applied DigComp in general education contexts without addressing the disciplinary nuances required for scientific learning. By integrating indicators such as simulation accuracy evaluation, virtual laboratory data interpretation, and digital identity security in scientific environments, the study provides a more precise framework for assessing digital competence in physics.

The mixed-methods approach enhances the depth of the analysis by combining quantitative profiling with qualitative explanations for the observed competence gaps. This design offers a richer understanding of digital competence development, connecting numerical scores with contextual factors and student experiences. As such, the study contributes to the refinement of DigComp-based assessment tools and provides a foundation for future work in discipline-specific digital literacy research.

The findings underscore the need for curriculum interventions that explicitly target critical and protective digital competencies. Simply integrating digital tools into coursework is insufficient; students must be taught how to evaluate scientific information, validate experimental results, and apply security principles in digital laboratory environments. This requires redesigning course structures to move beyond tool usage and toward epistemic engagement with digital resources.

Additionally, curricula should provide structured opportunities for students to explore and compare different digital tools, promoting self-directed competence rather than reliance on lecturer guidance. Physics programs must encourage the use of scientific software, computational tools, and analysis platforms that align with the epistemic demands of the discipline.

Based on the imbalance of competencies identified in this study and the qualitative findings that reveal structural causes of these weaknesses, several curriculum interventions can be developed as follows.

1. Integration of Digital Science Case-Based Problem-Based Learning (PBL)

The low Information Evaluation score (73 %) and students' reliance on visual appearance to judge credibility indicate the need for structured training in data verification. Case-based PBL activities should require students to analyze scientific misinformation, validate virtual laboratory results, and assess the evidential quality of simulation-based data.

2. Cybersecurity Module for Pre-Service Physics Teachers

Given that Digital Safety received the lowest score (69.6 %), a dedicated cybersecurity module is essential. Content should include password management, secure LMS practices, digital identity protection, and the ethical handling of experimental data. Training should emphasize hands-on practice rather than theoretical instruction alone.

3. Authentic Training Using Digital Laboratories

Theme 1 and Theme 4 show that students use technology mainly when directed to do so. Courses such as Computational Physics or Virtual Laboratory Practice should incorporate sensor-based experiments, data acquisition tools, and simulation analysis to promote deeper engagement with scientific digital tools. These activities will strengthen both scientific reasoning and digital problem-solving skills.

4. Benchmarking Against Global Standards (ISTE and DigCompEdu)

To align with international best practices, physics education programs should evaluate their curricula using the ISTE Standards and DigCompEdu frameworks. These standards emphasize

reflective digital practice, scientific data literacy, and safe integration of technology, which correspond directly to the areas where competence gaps were identified.

CONCLUSIONS

This study reveals that pre-service physics teachers possess relatively strong operational digital skills yet continue to exhibit weaknesses in critical and protective domains, resulting in an overall imbalanced digital literacy profile. These findings underscore the urgent need for physics education curricula that more explicitly cultivate evaluative, epistemic, and safety-oriented digital competencies through technology-enhanced learning activities and the reinforcement of 21st-century skills.

Furthermore, this study contributes to strengthening DigComp-based digital competence assessment in Indonesia by applying several adapted indicators specifically tailored to physics education contexts. The resulting instrument and methodological approach offer a valuable reference for more standardized and discipline-sensitive assessment practices in higher education.

Overall, this study enriches the literature on the digital competence of pre-service physics teachers and opens pathways for future research, including broader sample testing, instrument validation through advanced psychometric analysis, and longitudinal investigations aimed at mapping digital competence development over time.

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