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ORIGINAL

Student Literacy for Shifting from Digital to AI literacy: Mapping Domains, Indicators, and Gender Differences

Preparación Estudiantil para la Transición de la Alfabetización Digital a la Alfabetización en Inteligencia Artificial: Un Análisis de Dominios, Indicadores y Diferencias de Género

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ABSTRACT

Introduction: as artificial intelligence (AI) became increasingly integrated into education, AI literacy emerged as a key component of digital literacy, particularly in the context of Society 5.0. Digital literacy expanded beyond access and usage to include critical interaction with, creation of, and adaptation to intelligent technologies. For adolescents, these skills were essential for meaningful engagement in AI-based science learning. However, valid instruments to measure AI literacy in adolescents, remained limited. This study aimed to (1) identify and define the domains and indicators used to measure students' AI literacy skills in Indonesia; (2) assess the overall level of AI literacy among Indonesian students; and (3) examine gender-based differences in AI literacy levels.
Method: the study followed three stages: item construction based on literature review, expert validation, and empirical testing using Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA). EFA was conducted with 219 adolescents to explore the scale structure, followed by CFA with 220 adolescents to confirm the model.
Results: the validated scale consisted of four factors: Technology Skills (3 items), Using Digital Information (6 items), Creating Digital Information (2 items), and Awareness in the Digital World (3 items). While students demonstrated high overall digital literacy, weaknesses were observed in technology skills and content creation. No significant gender differences were found.
Conclusions: the study emphasized the importance of schools in promoting not only digital use but also content creation. The validated scale provides a reliable tool for supporting structured digital literacy education as a foundation for AI literacy.

Keywords: Digital Literacy; Artificial Intelligence Literacy; AI Literacy; Adolescents; Gender Differences.

RESUMEN

Introducción: a medida que la inteligencia artificial (IA) se integra cada vez más en la educación, la alfabetización en IA ha emergido como un componente clave de la alfabetización digital, particularmente en el contexto de la Sociedad 5.0. La alfabetización digital ha evolucionado más allá del simple acceso y uso, para incluir la interacción crítica con tecnologías inteligentes, así como la creación y adaptación a estas. Para los adolescentes, estas competencias son esenciales para una participación significativa en el aprendizaje de ciencias basado en IA. Sin embargo, los instrumentos válidos para medir la alfabetización en IA en adolescentes siguen siendo limitados. Este estudio tuvo como objetivo: (1) identificar y definir los

dominios e indicadores utilizados para medir las habilidades de alfabetización en IA de los estudiantes; (2) evaluar el nivel general de alfabetización en IA entre los estudiantes; y (3) examinar las diferencias de género en los niveles de alfabetización en IA.
Método: el estudio se desarrolló en tres etapas: elaboración de ítems basada en la revisión de literatura, validación por expertos y pruebas empíricas mediante Análisis Factorial Exploratorio (EFA) y Análisis Factorial Confirmatorio (CFA). El EFA se realizó con 219 adolescentes para explorar la estructura de la escala, seguido del CFA con 220 adolescentes para confirmar el modelo.
Resultados: la escala validada consistió en cuatro factores: Habilidades Tecnológicas (3 ítems), Uso de Información Digital (6 ítems), Creación de Información Digital (2 ítems),) y Conciencia en el Mundo Digital (3 ítems). Aunque los estudiantes demostraron un alto nivel general de alfabetización digital, se observaron debilidades en habilidades tecnológicas y creación de contenido. No se encontraron diferencias significativas por género.
Conclusiones: el estudio destacó la importancia del rol de las escuelas en promover no solo el uso digital, sino también la creación de contenido. La escala validada proporciona una herramienta confiable para apoyar una educación estructurada en alfabetización digital como base para la alfabetización en IA.

Palabras clave: Alfabetización Digital; Alfabetización en Inteligencia Artificial; Preparación para la IA; Adolescentes; Diferencias de Género.

INTRODUCTION

Currently, most educational policies and practices in school are still focused on strengthening basic digital literacy, such as the ability to use digital devices, access information, and operate common software or applications. In contrast, AI literacy requires more complex competencies, including conceptual understanding of how AI works, ethical awareness in interacting with intelligent technologies, and the ability to create AI-based solutions.[1]

The rapid pace of digital transformation has significantly reshaped education at all levels, including in schools. On one hand, digital literacy has become a fundamental competency, enabling students to access information, communicate, and engage in online learning effectively. On the other hand, the rise of artificial intelligence (AI) technologies introduces a new and urgent demand: AI literacy, which involves understanding, interacting with, and evaluating intelligent systems in an ethical and responsible manner.[2,3]

In the context of education, especially for adolescents, the development of digital technology demands an expansion of the concept of digital literacy toward AI literacy. AI literacy is seen as an advanced phase of digital literacy,[4,5,6] which not only emphasizes basic digital skills but also the preparedness to think critically,[7] ethically,[8] and applicative about AI technology in the learning process.[9]

The rapid integration of AI into educational system has redefine the core competence for learners. AI Literacy has become a crucial aspect of modern education, requiring students to develop not only digital literacy, [10] but also an understanding of artificial intelligence and its ethical implications.[11] In recent years, many secondary schools have substituted a portion of physical teaching with online learning [12,13] then leading to a new challenge for adolescents.[14] However, many students have spent more time on social media and online learning [15,16] which requires different procedural understanding and norms.[17] Therefore, they need skills, including information and digital media literacies[12,18] the ability to recognize and respond to hoax news, and an understanding of appropriate media use.[19,20]

The young generation in this computer and internet era is inseparable from the digital realm, and is referred to as "Generation Z". This means a society where people are emotionally attached to the digital world[21] and are considered to have "natural ability" to use technology.[14] Young people usually learn to operate the internet and computers by observing family members and through interactions with peers. This ability is increasingly widespread when they use it for schoolwork, for example, to obtain information, discuss, and make presentations and reports.

Adolescents naturally increase their technical competence and intellectual ability in handling digital information[13,22] with the aim of not being left behind by their peers. However, are they digitally literate? Does a high level of digital literacy among students automatically indicate literacy for AI? Or is there a gap between digital and AI literacy that needs to be addressed through curriculum design and targeted learning strategies? This question is difficult to answer because most research targeted at adolescents shows they evaluate themselves as experts and rate their competency level high. But in practice, even though they are active social media users, they are less qualified to be called proficient and productive in the digital world.[23,24] Therefore, information on students' capabilities is important for education stakeholders,[25,26] and they need to implement skills programs for those in high school. This will help them communicate in social environments,[27]

and promote digital literacy as a lifelong learning concept.[28]

CONCEPTUAL FRAMEWORK

Digital Literacy

The term digital literacy was coined from traditional definition and has grown in popularity. For that reason, digital literacy perception often overlaps with others, such as computer and information literacy.[29,30,31] Computer literacy is the ability to effectively use technology such as the internet, websites, and search engines.[32] Meanwhile, information literacy means obtaining, identifying, retrieving, evaluating, processing, and effectively using information.[32,33,34] Therefore, they are both known as digital literacy.[35] In recent publications, digital literacy has been referred to as the intersection of technical, cognitive, and socio-cultural skills.[11,25,35,36] It is defined as the ability to obtain, evaluate, utilize, share, and create content using information technology and the internet.[9] Furthermore, it involves capabilities in accessing, navigating, reading, as well as creating digital media.[19,37] This definition describes it as the ability to apply cognitive and technical skills. Also, cognitive skills allow individuals to discover, evaluate, create, and communicate information and content,[22] while technical skills are applied when using software and operating devices.[16,38]

This literacy is an individual's capability to live, learn, and work in a society, which are related to communication and collaboration using digital media, both in studying and working.[35,39,40] Therefore, a literate in this field refers to an individual with these capabilities. This is where communication and access to information are improving through technology such as internet platforms, social media, and mobile devices.[41,42] The cognitive dimension is associated with the ability to think critically when searching, evaluating, and creating information.[43] It also includes the ability to use and analyse text, visual or audio-based,[44,45] and understand the form, format, location, and method of accessing information resources.[36,46] It is the capability to use the internet, communication, and its products.[47,48] A widely accepted epistemology states that creation is a cognitive activity representation.[49] Furthermore, cognitive perspective refers to the ability to search, evaluate, and create information, which includes the use and production of digital sources.[45,50] However, this does not manifest by how many web pages are visited or how much information is read, but on the ability to select and effectively use information as well as integrate relevant ones from various sources.[8,45] From this perspective, it is known as how well adolescents apply cognitive frameworks in obtaining, identifying, retrieving, evaluating, processing, and using information, as well as creating contents.

The social-emotional dimension is associated with the ability of socio-structural literacy, which is how information is distributed and socially produced.[51] Also, the utilization of a digital environment for learning and communication should be carried out with responsibility, and reflecting norms and morals.[33] The socio-cultural dimension is an expression of the general individuals' ability to live, study, and work in a digital society,[52] and they recognize the changing and evolving nature of technology.[27] This perspective considers the DL concept not only as a skill set, but also more holistic, which is a meaningful individuals' function in the community.[47,53]. Furthermore, in developing digital literacy, young people are valued as part of the community through participation and knowledge production (reification).[28,47] For example, the youths of a community concerned about environmental conservation could be involved in both participation (e.g., criticizing environmental damage) and reification (e.g., researching and publicizing environmental damage). Both processes require digital skills, and contribute to literacy growth. Therefore, the socio-cultural perspective can be considered a process of conceptualizing digital literacy as a skill and competency, as well as contextualizing it in community practice.[9,47].

AI Literacy

The rapid advancement of artificial intelligence (AI) technologies has significantly reshaped our daily lives. As AI becomes increasingly embedded in smart devices and applications, the need to understand and define AI literacy has become more urgent. AI literacy refers to the essential knowledge and skills that enable individuals—particularly non-experts—to understand, critically assess, and effectively use AI technologies in various contexts.

According to [48] and [37] AI literacy involves a foundational understanding of AI systems, the ability to interact with them meaningfully, and the capacity to apply this understanding in diverse settings such as the home or workplace.[19] further emphasized the importance of practical skills in applying AI in everyday life.[52] broadened this definition by including the ability to critically interpret AI-generated outputs and maintain ethical and social awareness when using AI tools.

To provide a structured framework,[37] proposed four key dimensions of AI literacy: (1) foundational knowledge of AI concepts; (2) practical application of these concepts in learning environments; (3) critical evaluation of AI technologies within context; and (4) ethical reasoning related to AI use. Building on this,[35] categorized AI literacy into four measurable components: awareness, usage, evaluation, and ethics.

AI Literacy as an Extension of Digital Literacy

In the era of Society 5.0, digital literacy is no longer limited to the ability to access, understand, and use digital tools.[4,54] It must evolve to encompass AI literacy is the capacity to critically interact with, adapt to [52,55,56] and co-create with intelligent technologies.[37] This conceptual framework positions AI literacy as a higher order extension of digital literacy, integrating foundational digital skills with emerging competencies relevant to artificial intelligence.

- The framework builds on four core dimensions of digital literacy:
- Technology Skills: operational abilities in using digital devices and platforms;
- Using Digital Information: the ability to search, filter, evaluate, and utilize digital content;
- Creating Digital Information: the capacity to produce digital content meaningfully and ethically;
- Awareness in the Digital World: including data privacy, security, and responsible behavior.

AI literacy extends these by introducing three interconnected capacities:[1]

- AI Usage Competence: using AI applications to enhance daily life and learning;
- AI Literacy and Understanding: grasping the logic, strengths, and limitations of AI systems;
- AI Ethics and Responsibility: critically reflecting on AI's societal impacts and ethical implications.

This framework asserts that fostering AI literacy in adolescents requires reinforcing core digital literacies while deliberately integrating AI focused competencies into education. It provides a scaffold to evaluate how well students are prepared not only to consume but also to critically engage with and shape AI technologies within science learning and beyon. AI literacy does not replace digital literacy, but rather builds upon it as a foundational layer.

Gender in digital literacy

Several studies showed gender does not contribute to digital literacy competencies.[57] On the contrary, some studies explained computer skill differences between genders[58,59] which might result in digital literacy differences. The patterns in students' use and skills, their perceptions, and their sense of competence in using computer technologies are subject to gender differences[60] that might be associated with the differing development of students' literacy.[60,61,62] These differences may affect classroom interactions as well as learning processes and have therefore to be considered carefully by teachers who apply computer technologies supported learning.[63,64] So, educators must recognize the importance of ensuring that all students can have sufficient digital skills. Therefore, research to ascertain the gender differences is required.

Research objectives

As cited from the Ministry of Communication and Informatics, Indonesia has the eighth highest number of internet users in the world, but ranks 56th in digital literacy as of 2022. In developing digital literacy education, an assessment is needed to map adolescents in the country. However, the validity and reliability of the assessment have not been examined.[65] Therefore, this research's objective is to answer the problems:

- What are the domains and indicators to measure students' AI literacy skills in Indonesia?
- What is the level of AI literacy of Indonesian students? And
- Is the level of AI literacy of students in Indonesia the same for each gender?

The research began by developing a questionnaire with an exploratory approach, and through a stringent psychometric series. The resulting instrument becomes an alternative tool for educational stakeholders to assess and determine digital literacy level in adolescents. Therefore, this instrument is a complement to self and peer assessment that is widely developed to measure literacy in adolescents.

METHOD

Participants

The participants were grade 10-11 adolescent across several senior secondary schools in East Java. The samples were 439 students with a range of 15-17 years, which consisted of 261 females and 178 males, aged between 15 and 17 years. According to the World Health Organization (WHO), individuals aged 10–19 years fall within the *adolescence* category, with 15–17 years classified as *middle adolescence*. This classification is crucial in understanding their cognitive, social, and digital literacy development. These students were enrolled in different academic tracks, including science and social studies. In their school Information and Communication Technology (ICT) is integrated into the school curriculum, either as a mandatory subject or embedded within other subjects such as science and digital skills training. However, the depth of ICT education varies across schools, with some providing specialized computer-based learning while others emphasize general digital literacy skills.

Research procedure

The research procedure involves developing the Digital Literacy Scale (DLS) and AI Literacy Scale (ALS), data collection, and analysis. The DLS and ALS was developed through three main stages. Firstly, a review of some relevant literature using the keyword "digital literacy" and AI Literacy. The results of this review were used to determine the key factors of digital literacy and AI Literacy. Furthermore, a literacy questionnaire with 4 factors was developed, which are Technology Skills, Digital Information use, Creating information, and Awareness in the Digital World (table 1). The key elements of these factors are identified and organized into questionnaire items, each with choices: strongly agree, agree, doubt, disagree, and strongly disagree. Secondly, the draft was reviewed by 6 education experts, and the input they provided was used for revision. Thirdly, the questionnaire was given to 20 participants to test reability. Therefore, a set with 18 statement items was obtained.

Table 1. Factors and elements of digital literacy

Factors	Element
Technology Skills	Understanding technology as an important tool to facilitate communication and strengthen information sharing.[28] Skillful use of internet browsers and search engines.[66] Learn in a digital society and recognize the changing nature of technology.[27] Technological skills are needed to be digitally literate, both in academic, social and future lives.[28]
Using Digital Information	Able to access, manage, integrate, and evaluate information, including intelligent selection and information use through technology.[28] Organize and integrate information.[45] Creating meaning and communicating effectively with others, including the ability to use visual representations, integrate various digital texts, navigate non-linear texts, and evaluate information.[55] Competent in obtaining, processing, producing, and communicating information as well as fluency in online technology, communication norms, applications, and programming field.[35] The ability to use digital technologies to access, evaluate, create and communicate information in a socially responsible and ethical manner.[48]
Creating Digital Information	Demonstrates the ability to critically evaluate and analyze digital material, including questioning information sources, evaluating the interests and objectives of information producers.[67] Become an active content producer rather than a passive consumer.[53] As a creative digital media producer.[13] Become a digital content creator and producer.[20] Be smart, responsible, and understand ethical consequences when using online media, and in making decisions.[37]
Awareness in Digital World	Digital literacy aims to produce active and caring citizens.[28] Locating and producing information socially by considering responsibility and morals.[36] Having social awareness in a digital environment.[68]

Data collection and analysis

Digital Literacy Scale (DLS) was implemented in 439 teenagers in grades 10-11 in senior secondary school. Participants filled out this scale for 30 minutes, carefully corrected and the results were recorded in Microsoft Office Excel. The first objective was to produce a digital literacy scale and its main factors. Also, the first sub-sample data from 219 participants consisting of 151 women and 68 men were used for Exploratory Factor Analysis (EFA). Then, the second data from 220 participants consisting of 110 women and 110 men participated in Confirmatory Factor Analysis (CFA). The second objective was to outline digital literacy in adolescents, and the participants' data were analyzed. The third objective was to ascertain whether there's a digital literacy difference between males and females. Descriptive analysis was used to calculate the mean and standard deviation of the total score or per factor, and higher scores indicate more ability. Also, an independent sample t-test was used to determine differences based on gender.

RESULTS

Item Analyses

Before conducting factor analysis, descriptive analysis has been completed to examine all mean and standard deviation (SD). This showed the mean is in the range of 3,35 to 4,11 (SD = 0,59 to 0,93). Therefore, 18 items below 2,5 SDs were retained as the criteria. The question items with correlation value of ≤ 0,80 were also maintained.[69] Based on the results with Pearson correlation, r is in the range of 0,376 to 0,629, with a p value of 0,000.

Exploratory

Examination by Kaiser-Meyer-Olkin *factor analyses* (KMO) and Measures of Sampling Adequacy (MSA) was performed to evaluate the sample accuracy. The results showed 0,846 KMO value, with MSA value of all items > 0,5 (0,681 to 0,939). Referring to the criteria,[70] the sample used was valid. Analysis with Bartlett's test value showed the value x2 (153) = 1270,3, p = 0,000, which was normally distributed, adequate for factor analysis, and showed good accuracy results. Therefore, there was no need to modify or eliminate the questions in the questionnaire.EFA analysis with Varimax rotation produces 4 factors with a total variance of 56,79 %, which is normal in social studies.[71] These four factors consist of 18 initial items with the most reliable structure of more than 0,5 and no cross-loading. Furthermore, 0,5 threshold was taken as the recommendations[72] for a sample size of 200. The four identified factors (*see* Appendix) are as follows:

- Factor 1- Technology Skills. This consists of 6 items with a 0,551 to 0,669 loading factor, an eigenvalue of 5,521, and 30,67 % variance. This is a representation of technology skills, which includes internet browsers and search engines. It also recognizes the evolving nature of technology.
- Factor 2- is Digital Information Use. This consists of 6 items with 0,533 to 0,831 loading factor, an eigenvalue of 1 833, and 10,18 % variance. This factor illustrates the ability to access, manage, integrate, evaluate, intelligently select and use information through technology.
- Factor 3- Creating Digital Information. This consists of 3 items with a 0,740 to 0,833 loading factor, an eigenvalue of 1 573, and an 8,738 % variance. This represents the ability to create digital content by integrating various information through social, moral, and ethical responsibilities.
- Factor 4- Awareness in the Digital World. This consists of 3 items with 0,681 to 0,754 loading factor, an eigenvalue of 1 296, and a 7,2 % variance. This demonstrates social awareness's importance in the digital world, such as being involved and giving opinions in protecting the environment and global peace.

Confirmatory factor analysis

CFA validation uses a correlated model toward 8 items. The 4 factors resulting from EFA show less match with the goodness-of-fit statistical value, x^2/df = 2,397, RMSEA = 0,08, SRMR = 0,043, CFI = 0,847, GFI = 0,846, NFI = 0,767, and TLI = 0,818. Furthermore, the estimated value of standardized regression weights (λ) showed there were three items with a λ value less than 0,5. Also, checking for modification indices allowed covariance between e11 and e12 (error terms of items 7 and 8). Deleting the three items to strengthen the construct variables, and covariance e11 and e12 information could increase the match values to good levels. This is accepted based on the criteria x^2 /df ≤ 3,[10] SRMR < 0,08 and RMSEA < 0,06 (Hooper et al., 2008), CFI, GFI, NFI, and are close to or more than 0,90.[73] The goodness-of-fit statistical value after the revision are x^2/df = 2,20, RMSEA = 0,074, SRMR = 0,04, CFI = 0,914, GFI = 0,912, NFI = 0,855, and TLI = 0,886. The factors structure with correlated models can be seen in figure 1.

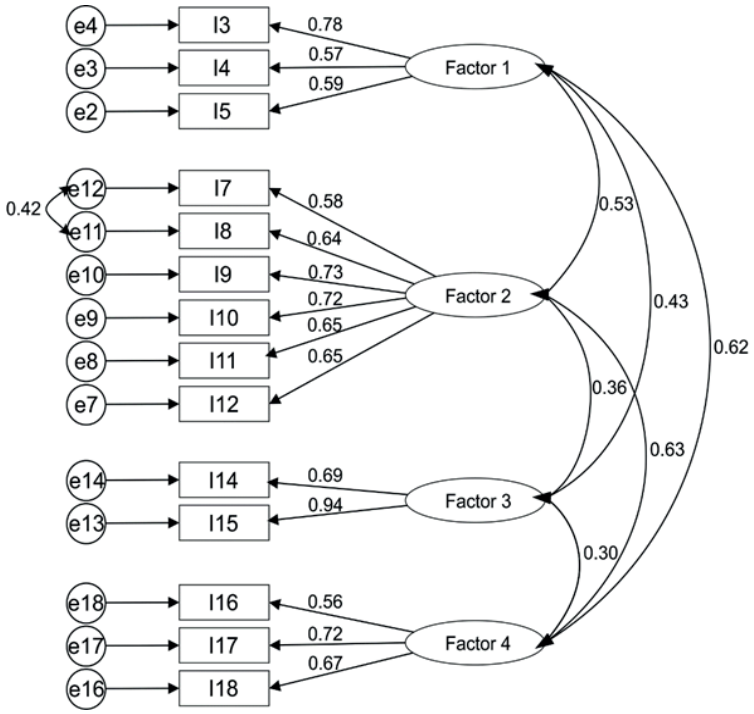

Figure 1. Four-factors correlated model of the Digital Literacy Scale

Internal Consistency

Internal consistency analysis consist of Cronbach's alpha (α), Construct reliability (CR), Average Variance Extracted (AVE), and concurrent validity. The minimum threshold values of α, CR, and AVE based on recommendations are ≥ 0,6, ≥ 0,7, and ≥ 0,5 respectively. Also, the α value met the minimum threshold, and CR starts from 0,69 to 0,81. Although they have not yet reached the minimum threshold, they are close to the prerequisite values. Furthermore, AVE values start from 0,42 to 0,67. Although most factors have not yet reached the minimum threshold, the value above 0,4 still showed good strength. Also, the α, CR, and AVE values details can be seen in table 2. The concurrent validity examination was performed by calculating the correlation between the factors and Pearson (table 3). The result showed all factors correlated positively and significantly with each other. The value of r= 0,272-0,440 s is classified as moderate and meets the requirements of r ≤ 0,80.[69]

Table 2. CR, AVE, and α of 14 items & 4 factors of digital literacy

Factors	Criteria			
	λ	CR	AVE	α
Factor 1. Technology Skill				
I3	0,783			
I4	0,568	0,69	0,43	0,69
I5	0,594			
Factor 2. Digital Information Use				
I7	0,581			
I8	0,541			
I9	0,729	0,81	0,42	0,81
I10	0,723			
I11	0,651			
I12	0,646			
Faktor 3. Creating Digital Information				
I14	0,688	0,80	0,67	0,78
I15	0,937			
Faktor 4. Awareness in Digital World				
I16	0,561			
I17	0,724	0,69	0,43	0,67
I18	0,666			
Total				0,84

Table 3. Concurrent validity

Item	Factor 1	Factor 2	Factor 3	Factor 4
Factor 1	1			
Factor 2	0,422**	1		
Factor 3	0,272**	0,318**	1	
Factor 4	0,440**	0,473**	0,272**	1

Table 4. Students' digital literacy profiles

Factor	M	SD	Rank
Technology Skills	3,74	0,63	Using Digital Information > Awareness in Digital World > Creating Digital Information > Technology Skills
Digital Information Use	4,02	0,52	
Creating Digital Information	3,80	0,79	
Awareness in Digital World	4,00	0,64	

Table 5. Means (SD) of digital literacy by gender

Factor	Male	Female	t	p
Total	3,92 (0,52)	3,86 (0,40)	-0,938	0,327
Technology Skills	3,86 (0,69)	3,61 (0,55)	-2,911	0,004**

Digital Information Use	4,01 (0,51)	3,96 (0,52)	-1,636	0,103
Creating Digital Information	3,83 (0,84)	3,77 (0,74)	-0,513	0,608
Awareness in Digital World	3,92 (0,67)	4,08 (0,61)	1,927	0,055
Note: ** p < 0,01				

Level of digital literacy skills and gender effect

The digital literacy profile (table 4) showed the total score mean to be 3,89 out of 5. This indicated that their ability is relatively high. According to the mean of each factor, the highest to lowest are Digital Information Use, Awareness in Digital World, Creating Information, and Technology Skills. The differences between males and females were calculated using the Independent sample *t*-test (table 5), and the results showed no digital literacy differences exist between the two genders. Furthermore, each factor analysis showed significant differences were detected only in Technology Skills.

DISCUSSION

This study produces a digital literacy scale with factors, and items numbers which are Technology Skills (3 items), Digital Information use (6 items), Creating Information (2 items), and Awareness (3 items). These four factors already represent literacy essentials.[28,36,74] Technology Skill factors focus on competencies of using digital technology such as computers, the internet, and search engines.[75] These skills are useful for accessing information, online learning, and for socializing.[12] However, participating in the cyber world requires basic skills for using computers, gadgets, laptops, searching for information by keywords, navigating web pages, and using the menu structure.[58] Also, technology skill level affects the quantity and quality of internet use.[49] This instrument has 3 items which represent skill level, which are the ability to use the internet to obtain information, learn, and socialize (fluency level), use search engines to access various sites (skilled level), and the level of life-long-skilled learners.[67]

Furthermore, using Digital Information incorporates the entire process of understanding, skills, attitudes, into the implementation.[74] call it problem-solving practice to obtain, access, analyse, and critically evaluate information. Those that are digitally literate are able to find, access, understand, analyse, and evaluate information, and can also use it for their daily interests by following norms and ethics.[76,77] The dimension of Creating Digital Information highlights participation in content creation. This transformation is driven by innovation and creativity. Also, creating has become an important dimension for all students in the digital world,[13] and it is supported by the use of information, technical and digital skills. This dimension includes writing a blog, creating animations, video production, using apps and virtual reality for learning, which is one aspect of digital literacy.[42]

The last dimension is Awareness. The world today has various problems and issues such as global warming, energy, pollution, environmental degradation, and wildlife conservation, which require public awareness.[78] Therefore, the purpose of digital literacy education is to build citizenship awareness.[37] Despite its limitations, schools can function as laboratory for the development of critical social reality interpretations, which include utilizing this literacy to promote social awareness.[44,68,79] This is important for people in developing countries like Indonesia, which faces many new problems caused by cyber technology globalization.

Students' Digital Literacy and Gender Differences: Implications for AI Literacy

The results presented in table 4 show that students demonstrated relatively strong digital literacy, particularly in the domain of Digital Information Use (M = 4,02, SD = 0,52) and Awareness in the Digital World (M = 4,00, SD = 0,64). However, their performance in Technology Skills (M = 3,74, SD = 0,63) and Creating Digital Information (M = 3,80, SD = 0,79) was comparatively lower.

These findings indicate that while students are competent in accessing, evaluating, and ethically engaging with digital content, they still face challenges in more active and technical components of digital literacy. These components—particularly technology skills and digital content creation—are critical precursors to AI literacy, which requires students not only to consume and navigate information but also to interact with, adapt to, and create using AI-driven technologies.

From the perspective of AI literacy, these gaps suggest that students may not yet possess sufficient operational or creative skills to meaningfully engage with AI applications, such as coding, training models, or using AI tools for problem-solving. Therefore, their current digital literacy profile points to partial literacy for AI literacy, emphasizing the need for targeted instructional strategies to strengthen the technical and production-related aspects of literacy.

As shown in table 5, overall digital literacy scores between male (M = 3,92, SD = 0,52) and female (M = 3,86, SD = 0,40) students did not differ significantly. These findings highlight a gender gap in the technological dimension of digital literacy, which could potentially influence future engagement with AI tools. Since AI

literacy includes the ability to operate intelligent technologies, develop AI-based solutions, and understand the mechanisms behind them, stronger technology skills provide a notable advantage. Hence, male students may currently have a higher literacy level for AI-related tasks due to their technical edge, whereas female students appear stronger in ethical awareness—a crucial but different facet of AI literacy.

To promote equitable AI literacy, educational interventions must be gender-responsive, ensuring that all students are equally supported in developing both technical and ethical competencies. Bridging this gap is especially important as AI technologies increasingly become part of academic and professional environments.

Expanding Toward a Multidimensional AI Literacy Model

While this study validated a four-factor model representing core components of digital literacy, broader models of AI literacy have been developed to address emerging technological demands. For example, figure 2 illustrates an eight-factor confirmatory factor analysis (CFA) model with 31 indicators,[2,56,68,79] encompassing dimensions such as ethical concern, creative digital production, and lifelong learning literacy.[7,78] This model reflects a growing consensus that AI literacy requires more than technical and information skills. It includes higher-order capabilities such as adaptability, collaboration, and awareness of ethical implications—skills that are central to navigating Society 5.0. The present study's four-factor DLS can be seen as a foundational structure upon which more comprehensive frameworks like this can build. Future research may explore the integration of these extended dimensions to develop instruments that not only assess basic digital competencies but also evaluate students' literacy to engage meaningfully with AI-driven technologies.

The digital literacy results presented earlier (table 4 and table 5) indicate that students demonstrate high levels of Digital Information Use and Awareness in the Digital World, yet show lower competencies in Technology Skills and Creating Digital Information. While these domains provide an essential foundation for engaging with digital environments, they do not fully represent the multidimensional demands of AI literacy.

This gap becomes more evident when analyzed in relation to the eight-factor model of AI literacy, confirmed through Confirmatory Factor Analysis (CFA) in figure 2. Each latent factor corresponds to a distinct dimension of AI literacy, ranging from AI Application in Daily Life to Emotional Regulation during AI Interaction. These domains go beyond traditional digital literacy by integrating higher-order cognitive and affective competencies.

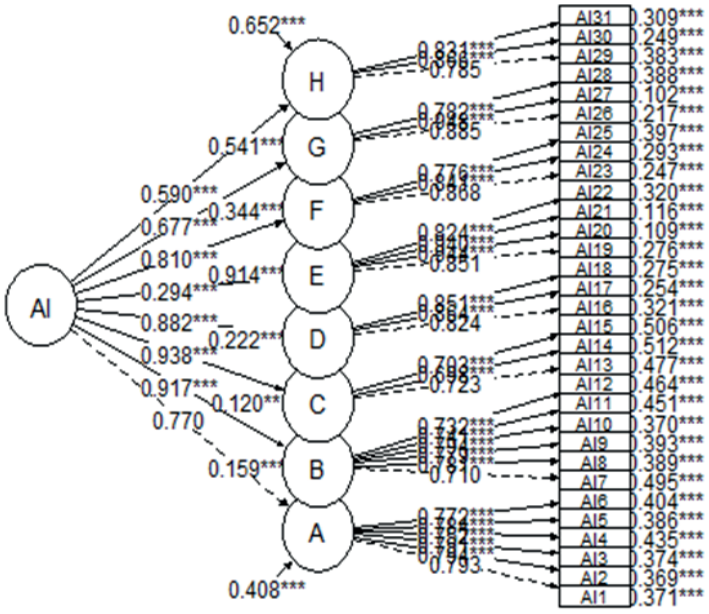

Figure 2. Confirmatory factor analysis (CFA) model with eight AI literacy dimensions and 31 indicators (adapted for comparison purposes)

In a broader AI literacy framework, such as the model with eight dimensions and 31 indicators (figure 2), key domains include daily AI application, conceptual understanding, ethical awareness, technical development, persuasion literacy, and emotional regulation. These competencies go beyond basic digital literacy and reflect a more holistic literacy to interact with AI across social, technical, and cognitive domains. For instance, this model includes dimensions such as: (1) AI Application in Daily Life (e.g., interacting with AI tools for daily tasks); (2) Conceptual Understanding of AI; (3) AI Interaction Awareness ; (4) Ethical Awareness; (5) AI Development Skills; (6) Problem Solving with AI; (7) AI Persuasion Literacy; (8) Emotional Regulation during AI Interaction. A more detailed breakdown of these eight dimensions and corresponding items is presented in table 6.

While the four-factor DLS validated in this study effectively captures foundational digital literacy, that's is: spanning technology skills, information use, content creation, and digital awareness, it does not explicitly address certain advanced competencies required for comprehensive AI literacy. In contrast, the eight factor AI literacy model (table 6) extends beyond these basics to include critical dimensions such as ethical awareness, technical AI development, persuasion literacy, and emotional regulation. The DLS can therefore be seen as an essential first-tier instrument, well-suited for large-scale adolescent assessments. However, as AI technologies become increasingly embedded in education and everyday life, scaling up toward a more multidimensional AI literacy framework is necessary. Such development would better inform curriculum policies, teacher training programs, and personalized learning strategies for Society 5.0.

Table 6. Eight Dimensions of AI Literacy and Corresponding Indicators

Factor Code	Dimension Name	Core Competency	Example Items
1 (A)	Daily AI Application	Using AI tools to support daily tasks	I can use AI to help me complete daily tasks efficiently.[80]
2 (B)	Conceptual Understanding of AI	Understanding AI definitions, opportunities, and limitations	I know the most important concepts related to AI.[81]
3 (C)	AI Interaction Detection	Recognizing AI-based technologies in real life	I can recognize when I'm interacting with AI vs. a human.[81]
4 (D)	Ethical AI Awareness	Considering ethical and societal impacts of AI	I can assess the ethical implications of using AI applications.
5 (E)	Technical AI Development Skills	Ability to design, code, and build AI applications	I can develop or program an AI-based application.
6 (F)	AI-Based Problem Solving	Confidence in solving complex problems using AI	I can handle complex tasks when working with AI.[82]
7 (G)	AI Persuasion Literacy	Recognizing AI influence on thoughts/decisions	I can identify when AI tries to influence my personal decisions.[83]
8 (H)	Emotional Regulation in AI Interaction	Managing emotions (fear, frustration, euphoria) when interacting with AI	I can manage anxiety or excitement when using AI in daily life.[84]

A comparison between the 4 factor DLS and the 8 factor AI literacy model reveals that the DLS is well-suited for large-scale baseline assessments of adolescent digital literacy. In contrast, the multidimensional AI literacy model reflects a more holistic framework required to navigate AI systems critically, ethically, and adaptively. This broader model aligns with the educational demands of Society 5.0. The educational implications of moving toward AI literacy are significant.[79] Integrating components such as emotional regulation during AI interactions can foster students' resilience against emotionally manipulative algorithms commonly embedded in digital media.[23,29,56] Similarly, strengthening ethical awareness and persuasion literacy can help students become not only competent users of AI but also responsible as digital citizens who capable of making informed, ethical decisions in an increasingly automated world.

Looking ahead, future research should explore the validation and contextualization of this multidimensional AI literacy framework for high school and university students in Indonesia. This includes the development of robust instruments to assess higher-order thinking skills, ethical reasoning, and adaptive learning capacity traits essential for lifelong learners navigating a rapidly evolving digital society.

Assessing from the total score and factor, adolescents have a good level of digital literacy skills, and both males and females have no significant differences.[57] However, 2 factors still need to be improved, which are Producing Digital Information, and Technology Skills. Learning in school may not have emphasized the balance between the four literacy factors. Therefore, learning should not only use digital information, but also be motivated to integrate and create valid information.[84] It also provides an opportunity for students to participate in giving opinions about global problem resolution.[77,85] Digital skills in schools were enhanced to anticipate the development of these technologies (life-long learning).

Those that are good at obtaining needed information can effectively access relevant sources using well-designed search strategies, and critically evaluate the truth of information obtained from the internet.[8,80] Furthermore, they have the ability to disseminate only true information, as well as obey the ethics and law in utilizing online contents, which include recognizing copyright.[86] The e-learning process and social media assist both students and teachers to effectively communicate,[9] especially when they have learning difficulties. In the cyber world, it allows users to connect with others online by making friends or followers.

Adolescents are considered to be the main people of the digital world, and they have practiced choosing and using information through the internet.[74] In the modern era, literacy is a life skill, which is not only about their expertise in using devices, but also to carry out tasks in a digital environment to solve problems or generate

ideas.[87,88,89] Fortunately, this idea has been incorporated into the current curriculum, where information and communication technology are integrated with all subjects. It is expected that students can immediately apply digital skills to solve problems.[90] In summary, two things make digital literacy and technology reach a high level, which are its need in life and in learning.[67]

Computer, the internet, and online media require digital literacy education that builds each individual as a lifelong learner.[32,85] Therefore, it is important to educate adolescents to develop and survive in an internet-dominated world.[83] In entering the fourth industrial revolution, education has two important goals, which are preparing adolescents to enter the world, and to become digital citizens.[91,92,93,94] These citizens are individuals that are responsible for how they use technology to interact with people around the world. However, education faces a challenge to incorporate digital content into the subject curriculum without compromising the learning outcomes. An effective education combines pedagogical knowledge, content, and technology as the integration of digital resources into teaching, to improve subjects learning outcomes.[34] The biggest challenge may be the teachers because they were not born in the digital age and are considered as migrants who need to adjust to technology.[53,77] Therefore, they might be distressed when asked to teach with a digital system.[6]

In the digital world, students can join in a wide communication network, both with individuals and institutions throughout the world. This activity provides many possibilities to grow global awareness Therefore, teachers need to bring technology into the classrooms and provide clear direction about their usage. This approach will further involve students in global networks, and convert awareness into action. Hence, learning not only involves using digital information but also motivates students to create it by integrating a variety of valid ones. Also, it provides an opportunity for students to participate in giving opinions about global issues.

Although it has the potential to provide enormous value, the online world also has risks, especially for adolescents. One-third of people, both adolescents and adults, tend to rely on the Internet and social media to obtain and disseminate information. This media is the most effective choice in spreading information, including misinformation. With this challenge, education must strive to continue to develop critical thinking,[95,96] especially in assessing news obtained from the Internet and social media.

Furthermore, teaching digital literacy requires an ethical dimension, and adolescents need to understand how to behave and act in a digital environment.[81] Teaching is also challenging because teachers have to be concerned about what information is available online. The results of research that show the existence of a gender balance in digital literacy are encouraging,[29] where gender can be said not to be an issue that needs to be emphasized in a class that is supported by technology. Looking at the framework described by the approach to facilitating gender equality,[97] these results may be related to the teacher's habit of creating active and cooperative learning. However, seeing that there are still gaps in the technology skills factor, similar with previous studies.[43,51] This effort should need to be strengthened with other approaches such as restructuring class interactions,[94] to enable men and women to experience pleasant interactions and experiences. This might help in resolving low self-efficacy and attitude toward technology problems in women.[98,99]

The mapping of digital literacy domains to AI literacy competencies reveals a clear progression path that supports the development of an integrated literacy transition framework. As proposed, this framework emphasizes the evolution of basic digital competencies into more advanced AI-specific skills. For example, using digital information prepares students for critical understanding of AI systems, while awareness in the digital world underpins ethical reasoning and responsible AI use. Meanwhile, creating digital content and technical skills are foundational for participatory creation using AI tools, such as prompt design, AI-based coding, or content generation through generative AI.

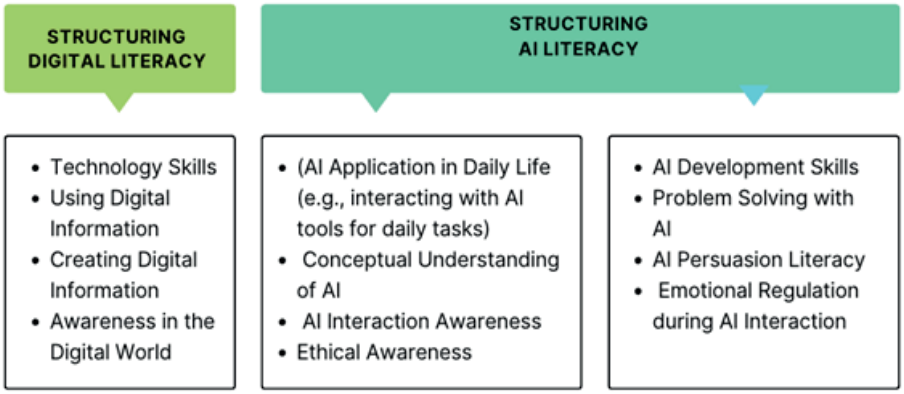

Figure 3. Structure between Digital literacy and AI Literacy

These relationships (figure 3) emphasize the urgent need for explicit educational strategies that do not

merely teach digital access or consumption, but rather prepare students to critically evaluate, ethically engage with, and actively produce using intelligent technologies.

CONCLUSION

This study presented a questionnaire to determine adolescent digital literacy with four factors, which are technological skills, digital information use, creating information, and awareness. The result showed this instrument has satisfactory internal validity, reliability, and consistency. The developed questionnaires can be used by education stakeholders to determine the digital literacy level in adolescents as well as evaluate the success of teaching it. The findings showed adolescents have good digital literacy, and it will not reduce the burden of education in preparing them for the future. Also, an open access to the internet could replace school's and teachers' role, although education remains important in developing them into digitally literate citizens.

Although this research contributes to encouraging digital literacy by providing an initial way to measure key constructs, more advanced work is needed in conceptualizing and measuring adolescent literacy. Furthermore, it includes better steps of cognitive processing through education. Although this research uses only adolescents in high school education level, future studies with a long-term focus on different levels are necessary. In addition, since increasing digital literacy proficiency is a major long-term goal, future research is also required to test the curriculum's effectiveness, including preparing teachers to become better digital literacy educators.

Importantly, this study highlights that digital literacy is only the starting point. As society increasingly transitions into an AI-driven era, digital literacy must evolve into a more comprehensive AI literacy framework. The validated four-factor DLS serves as a foundation, but future directions must explore additional dimensions critical to AI literacy, such as ethical awareness, emotional regulation, conceptual understanding of AI, and persuasion literacy. These competencies are essential for preparing students to thrive in Society 5.0—where human and machine collaboration is increasingly central.

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