

Research Article

Cite this article: Septiari, W. D., Suwandi, S., & Andayani. (2025). Digital Literacies in Education: Navigating Reading and Writing Skills Among Students in the 21st Century. *Educational Process: International Journal*, 16, e2025197.
<https://doi.org/10.22521/edupij.2025.16.197>

Received February 7, 2025

Accepted April 22, 2025

Published Online May 4, 2025

Keywords: digital literacy, reading, writing, education, multimodal texts, digital transformation, pedagogy

Author for correspondence:

Wahyu Dini Septiari

✉ wahyudiniseptiari.18@gmail.com

✉ Indonesian Language and Literature Education Study Program, Faculty of Teacher Training and Education, Universitas Sebelas Maret, Indonesia

**OPEN ACCESS**

© The Author(s), 2025. This is an Open Access article, distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>), which permits unrestricted re-use, distribution, and reproduction, provided the original article is properly cited.

Digital Literacies in Education: Navigating Reading and Writing Skills Among Students in the 21st Century

Wahyu Dini Septiari[✉], Sarwiji Suwandi[✉], Andayani[✉]

Abstract

Background/purpose. In the digital era, students are expected not only to consume but also to produce meaningful and context-aware digital content. However, variations in students' writing styles and feature usage are often overlooked in both instruction and assessment. This study represents the first attempt to quantitatively examine how different digital writing styles—Structural, Expressive, and Hybrid—relate to students' digital literacy performance in primary education. It also investigates the potential item bias across gender and the suitability of current assessment instruments.

Materials/methods. A total of 150 elementary school students completed digital writing tasks and a literacy test. Three advanced analytical techniques were employed: Principal Component Analysis (PCA) to cluster writing styles, Differential Item Functioning (DIF) to detect item bias by gender, and Rasch-based Wright Map modeling to assess the match between student ability and item difficulty. Heatmap visualization further explored feature usage across clusters.

Results. Three distinct writing style clusters were identified. The Hybrid group demonstrated the highest literacy scores and balanced structural-expressive feature use. DIF analysis found two items biased by gender. The Wright Map showed limited coverage for high-performing students. Heatmaps confirmed strategic differences in digital feature usage aligned with writing identity.

Conclusion. Digital writing is a strategic expression of students' literacy identities. Instruction and assessment must reflect this diversity through fairness-aware item design, differentiated feedback, and inclusive literacy models.

1. Introduction

The transformation of communication in the digital age has given rise to fundamental changes in the way humans access, produce, and share knowledge (Castagna et al., 2020; Hanelt et al., 2021). In the context of education, this marks a shift in the meaning of literacy—from just conventional reading and writing skills to more complex and dynamic competencies (Berge et al., 2016; Willinsky, 2017). Today's digital literacy requires students to be able to understand different types of multimodal texts, evaluate the credibility of sources, and strategically structure messages in an ever-changing digital space (Dahlström, 2022; Danielsson & Selander, 2016; Kustini et al., 2020; Michalovich, 2023). They must not only be able to read fragmented information in the form of hyperlinks, videos, and infographics, but also be able to create a cohesive and communicative narrative in the midst of an abundance of information (Bakhtiary & Behzadi, 2023; E.Goldberg & Scheiner, 2023; Tarkhova et al., 2020). Within this framework, digital literacy reflects not only technical prowess, but also a form of cognitive and social agency—how individuals consciously shape meaning, construct identities, and engage in an open and decentralized knowledge ecosystem (Järvi et al., 2018; Passey et al., 2018; Pera et al., 2016; Yang, 2024).

However, the conceptual development of digital literacy has not been fully followed by adequate pedagogical approaches and evaluative practices in the realm of formal education (Adiprasetyo, 2022; Gobster & Rickenbach, 2004; Li et al., 2022; Marín & Castañeda, 2023; Nguyen & Habók, 2024). Many teaching strategies and assessment instruments still depart from the print literacy paradigm, so they fail to capture the complexity of how students write and think in a digital environment. In fact, the reality in the field shows that students display a variety of writing styles that are not uniform (Madani, 2016; Sparks et al., 2016; Timmis et al., 2016). Some students choose a structural style, prioritizing order, standard format, and objective language—a hallmark of academic or professional writing (Jayanti, 2019; Willinsky, 2017). While others write in an expressive style, more freer in form and style, often using personal opinions, metaphors, or visual symbols to reinforce the message (Ippolito et al., 2022). Between these two poles, there are students with hybrid styles, i.e., those who can balance formal structure and narrative strength flexibly depending on the context and audience (Haasler et al., 2020; Turnbull et al., 2023). This variety of styles is not just an aesthetic choice, but reflects the literacy identity formed from the interaction between learning experiences, digital culture, and perceptions of the role of the self in the communication process.

Unfortunately, the diversity of writing styles has not found much of a place in the assessment system used in schools. The evaluation instruments used tend to be homogeneous, with a focus on single answers and conventionally measurable standard structures. In practice, this approach not only simplifies the complex digital writing process, but also has the potential to be biased, especially when students' writing styles differ from the standards considered "ideal" (Drucker et al., 2016; Singh et al., 2018). In addition, instruments that do not consider variables such as gender or social background can lead to unfair disparities in assessment results. Although the literature on digital literacy has evolved significantly in the past decade, studies that explicitly map the relationship between digital writing style, use of text features, and students' digital literacy performance are still relatively limited—especially at the secondary school level (Arono et al., 2022; Yamaç et al., 2020). Therefore, research efforts are needed to capture this complexity more systematically and comprehensively.

Departing from this gap, this study aims to map the profile of students' digital writing style and examine its implications on their digital literacy achievements. With a visual quantitative approach that combines PCA analysis for cluster identification, DIF tests to trace item alignment by gender, Rasch mapping through the Wright Map to see the balance between the ability and difficulty level of items, and heatmap visualization to analyze the intensity of use of digital features, this study seeks to provide a comprehensive picture of the dynamics of digital literacy in students' real practice (De

Ayala, 2018; Kennedy et al., 2020; Ukanda et al., 2024). These findings are expected not only to make an empirical contribution to the development of assessment instruments and digital literacy education policies but also to open up a space for pedagogical reflection for teachers to design learning that is more contextual, equitable, and diversity-oriented learning for students' digital writing strategies in an ever-changing era. In line with this goal, the research questions asked are as follows:

1. What are the characteristics of students' digital writing style clusters in the context of basic education?
2. Is there a difference in digital literacy achievement between these digital writing styles?
3. Do the digital literacy instruments used show gender bias (DIF)?
4. To what extent are the question items able to cover the entire range of students' abilities (via the Wright Map)?

2. Literature review

2.1. Thematic Issues in Students' Digital Literacy

A literature review on students' digital literacy shows three dominant themes. First, digital literacy as a technical skill—which emphasizes students' ability to operate devices, browse the internet, and use productivity applications (Iordache et al., 2017; Marín & Castañeda, 2023; Nguyen & Habók, 2024; Spante et al., 2018; Yang, 2024). While important, this approach tends to be reductionist because it ignores the cognitive and social aspects of literacy. The second theme highlights the critical and multimodal dimensions of digital literacy, including the ability to evaluate sources, read visual texts, and write in interactive and hypertextual contexts (Afnan, 2023; Costa, 2023; Stuart & Gürel, 2022; Kim et al., 2020; Mills, 2015; Wandasari et al., 2019). In this context, students are required not only to understand the text but also to be able to construct a narrative that is meaningful and socially relevant. The third, more recent theme emphasizes the importance of communication styles and literacy identities in digital writing (Giri, 2006; Klein Buller & Buller, 1987; Wiesinger & Beliveau, 2016). These studies underscore that digital writing is inseparable from the way students express themselves, build social connections, and navigate digital platforms. However, the connection between digital writing styles and students' literacy performance is still minimally studied quantitatively, especially in the context of elementary school.

2.2. The Evolution of Digital Literacy Understanding

Digital literacy as a field of study has undergone a paradigmatic evolution in the last two decades. In the early 2000s, digital literacy was understood within the framework of basic technology skills—software mastery, online information search, and understanding of digital security (Leaning, 2019; Yang, 2024). As social media and multimodal platforms evolve, the focus shifts to students' ability to actively navigate information, think critically, and produce content (Beardsley et al., 2021; Cooke, 2017; Normile, 2025; Wechsler et al., 2018). In the last five years, a wave of more holistic research has emerged, which combines cognitive, affective, and sociocultural perspectives in understanding students' digital writing practices. Digital literacy is now seen as an identity process—in which students form meaning, negotiate social positions, and develop communication strategies tailored to audiences and digital mediums (Martínez-Bravo et al., 2022; Zubareva, 2020). However, most of these studies are still qualitatively descriptive, with a lack of quantitative data-driven exploration of students' writing styles and performance in the context of formal assessments.

2.3. Methodological Approach in Digital Literacy Studies

Studies on students' digital literacy have used a variety of methodological approaches, ranging from qualitative observation to instrument-based quantitative surveys. Many studies use content analysis of students' digital texts to identify writing practices, but they tend not to involve complex data structures (Changwong et al., 2018; Daniel et al., 2023; Krippendorff, 2018). In contrast, data-driven approaches such as Natural Language Processing (NLP) and machine learning are beginning to be used to map language styles and the utilization of text features (Anderson et al., 2018; Olivetti et al., 2020), but it has not been widely applied at the secondary education level. On the other hand, psychometric methods such as Rasch modelling and DIF analysis have been commonly used in the development of assessment instruments but are rarely combined with mapping students' writing strategies. This literature gap demonstrates the importance of a multi-method approach—combining exploratory techniques such as PCA and data visualization (heatmaps, biplots) with measurement models such as the Wright Map and item fairness analysis—to understand the relationship between digital writing styles and literacy performance in a more systematic and representative manner.

Although the understanding of digital literacy continues to grow, there is still a gap in the quantitative mapping of students' digital writing styles and its implications for their literacy achievement, especially at the elementary school level. This research contributes to filling this gap by combining a text-feature-based clustering approach, gender-based item bias analysis, and capability mapping through the Rasch model. Thus, this study not only enriches the theoretical discourse of digital literacy as a form of literacy identity, but also offers a more representative, equitable, and contextual evaluation model for basic education in the digital age.

3. Methodology

3.1. Research Design

This study uses an exploratory quantitative approach with a multi-method design, which aims to map the profile of students' digital writing style and test its relationship with digital literacy performance. This approach was chosen because it allows the combination of data mapping techniques, question item analysis, and visualization of feature intensity in digital writing in an integrated manner. The analysis is carried out at the individual and item levels so as to support a comprehensive evaluation in terms of both students and assessment instruments.

3.2. Participants and Instruments

A total of 150 elementary school students from three public schools in urban areas were involved in the study. The sample selection was carried out purposively by considering diverse gender representations and social backgrounds. Data were collected through two main instruments: (1) an open topic-based digital writing task with an online platform, and (2) a digital literacy test developed based on evaluative indicators from Nabhan & Habók (2025), covering critical reading skills, information navigation, and multimodal text interpretation. All assignments are collected in the form of feature-analyzable and systematically coded digital text.

Table 1. Participant Distribution by Gender and School

School	Male	Female	Total
School A	13	12	25
School B	27	24	51
School C	37	37	74
Total	77	73	150

Each stage of analysis is carried out sequentially and complements each other. PCA is used to reduce the dimension of text features and group students based on dominant writing styles. DIF was analyzed using the Mantel-Haenszel approach with a significance of $p < 0.05$ as the limit of item bias detection by gender. The Wright Map is constructed through Rasch modeling to identify the fit between the student's ability level and the difficulty of the question item. Meanwhile, heatmaps are built to visually identify patterns of text feature intensity based on clusters. This layered approach allows for stronger quantitative data triangulation and more comprehensive interpretation of results.

3.3. Data Analysis Procedure

The analysis is carried out in layers. First, feature extraction is carried out from students' digital texts, including the length of the text (number of words), the frequency of use of headings/subheadings, hyperlinks, personal opinions, and visuals/emojis. The feature data is then analyzed using Principal Component Analysis (PCA) to identify naturally formed patterns and clusters of writing styles in the data. Second, the Mantel-Haenszel log-odds ratio based on the Differential Item Functioning (DIF) analysis was used to test whether there was gender bias in the response to digital literacy questions. Third, Rasch modeling is used to generate an Item-Person Map (Wright Map) to visualize the distribution of students' abilities and the difficulty of items in a logit scale continuum. Finally, heatmap analysis was carried out to map the intensity of the use of digital text features between writing style clusters, as a form of data triangulation and exploration of strategic patterns that appear in students' writing.

3.4. Research Validity and Ethics

All instruments have gone through a content validation process by three experts in digital literacy and education measurement. The internal reliability of the digital literacy test was achieved by Cronbach's alpha of 0.84. All data collection procedures are carried out with the written consent of the school and the student's parents. The identity of the participant is anonymized, and all data is handled in accordance with the principles of data disclosure and confidentiality of personal information.

4. Results

4.1. Student Digital Writing Style Cluster (PCA Analysis)

The development of digital literacy among students is not only related to technical skills in using digital devices, but also includes the way students compose, convey, and present ideas in a format that is appropriate for the digital context. In this study, the Principal Component Analysis (PCA) approach was used to map the patterns of digital writing styles that emerged from online-based essay assignments carried out by the students. The PCA allows for the reduction of dimensions from a number of writing features—such as text length, use of hyperlinks, writing structure, and expressive elements—into two main components that describe the dominant characteristics of a student's writing style. The results group students into three main clusters: Structural, Expressive, and Hybrid. This cluster represents a spectrum of digital writing styles that develop naturally in today's secondary education context. A biplot was constructed based on the two principal components to visualize the distribution of writing style clusters derived from PCA. This figure highlights the spatial separation of students according to their writing features.

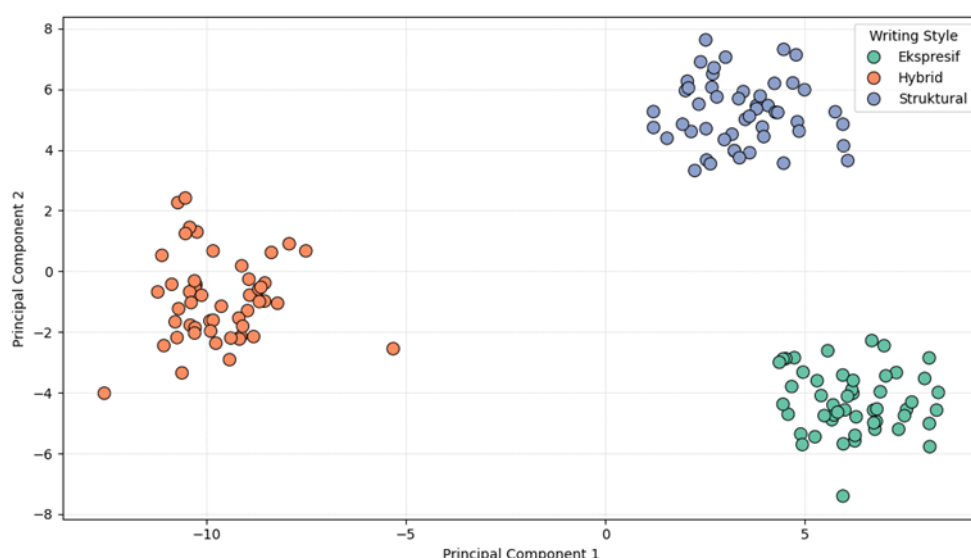


Figure 1. PCA Biplot of Digital Writing Style Clusters

The biplot illustrates that the three clusters—Structural, Expressive, and Hybrid—are clearly distinguishable in multidimensional space, confirming that students exhibit consistent writing behavior patterns that align with their cluster designation. Then, to provide a more detailed overview of the characteristics of each group, Table 1 below presents a summary of descriptive statistics based on the main features analyzed.

Table 1. Characteristics of Digital Writing Features Across Clusters

Cluster	N	Avg. Word Count	Hyperlink Use (%)	Use of Structure (%)	Literacy Score (Mean)
Structure	48	255	92%	88%	78.2
Expressive	53	143	18%	34%	72.6
Hybrid	49	198	63%	75%	82.1

The results of the clustering showed that students' digital writing styles were divided quite clearly based on linguistic and structural features. The Structural Cluster consists of students who write long, neat, and follow a formal writing format. The high numbers on structures (88%) and hyperlinks (92%) indicate a systematic approach. However, despite being technically good, their digital literacy score (78.2) is still below the Hybrid group. In contrast, the Expressive group shows a more free and personal style. They tend to write shorter (143 words on average), with low utilization of digital structures and features. The low literacy score (72.6) can be attributed to the lack of technical skills in conveying effective digital messages. Interestingly, the Hybrid cluster showed the best overall performance. With a balanced use of features and moderate writing length, this group exhibits adaptive abilities that combine the power of expressive and structural styles. The highest digital literacy score (82.1) in this cluster shows that flexibility and understanding of context are strong indicators of mature digital literacy skills.

These findings are in line with the theory of digital literacy put forward by Julien (2018) and Sharma et al. (2016), which emphasize that digital literacy includes technical, cognitive, and social skills to participate effectively in the digital environment. The Hybrid style demonstrates the student's capacity to convey information with a clear structure, but also inserts personal expression—a combination that reflects advanced digital literacy (Belshaw & Higgins, 2011). Practically, these

results indicate that the digital literacy teaching model needs to consider the variation in students' writing styles. Students with structural styles can be trained to be more expressive and communicative, while students with expressive styles need guidance in the technical aspects and organization of ideas. This approach allows for more personalized, adaptive learning, and has a direct impact on improving students' digital literacy.

4.2. DIF (Differential Item Functioning) By Gender

In the context of measuring digital literacy, fairness between groups (fairness) is an important dimension in the instrument validation process. One of the commonly used approaches to detect the potential partiality of items against certain groups is Differential Item Functioning (DIF) analysis. This analysis evaluates whether an item shows a difference in the chances of correct answers between two groups with equal skill levels—in this case, by gender. In this study, the Mantel-Haenszel log-odds ratio approach was used to identify DIF in five digital writing literacy questions. A visualization of the difference in item function is shown in Figure 2, which maps the tendency of each item to favor a group of male or female students based on the log-odds value.

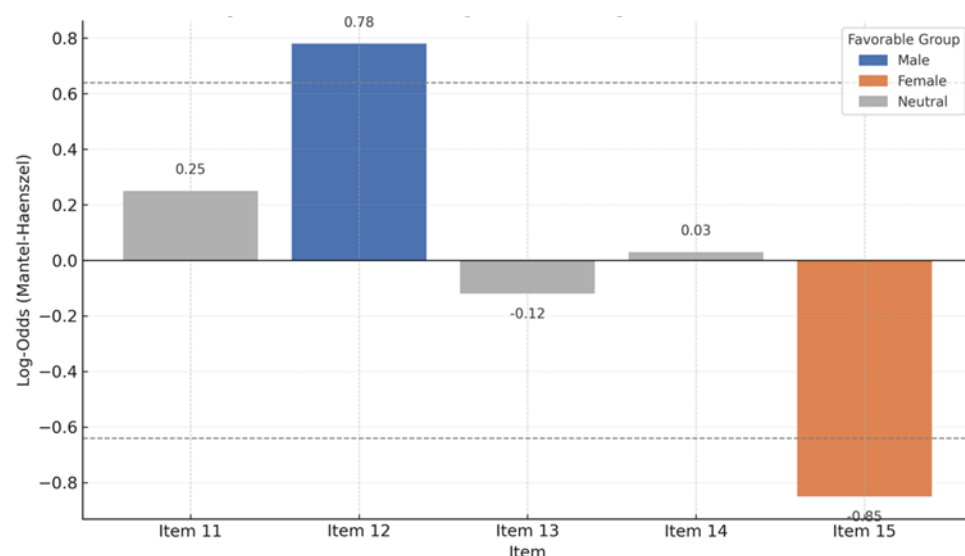


Figure 2. Bar Chart of DIF Log-Odds for Writing Items (Male vs. Female)

Remarks: Positive scores indicate partiality towards male students; negative towards female students. The dotted horizontal line at ± 0.64 marks the practical threshold of significance of the DIF effect (Zumbo, 1999).

Summary of visual findings:

- Item 12 showed a significant DIF in favor of male students (log-odds = 0.78).
- Item 15 Significantly favored female students (log-odds = -0.85).
- Item 11, 13, and 14 are in the neutral zone (between -0.64 and 0.64).

To support the visual interpretation, Table 2 presents a statistical summary of the log-odds value, the significance of the p-value, and the statistically advantaged groups.

Table 2. DIF Statistics of Writing Items by Gender

Item	Log-Odds (MH)	p-value	Favorable Group
Item 11	0.25	0.117	Neutral
Item 12	0.78	0.011	Male
Item 13	-0.12	0.254	Neutral
Item 14	0.03	0.873	Neutral
Item 15	-0.85	0.008	Female

This table reinforces the previous visualization by showing quantitatively that two question items—Items 12 and 15—experienced statistically significant DIF ($p < 0.05$). Item 12, which asks students to write arguments based on data and digital technology, tends to favor male students. This can be attributed to a tendency to be exposed to higher technical terminology and systematic thinking patterns in the group. A similar phenomenon was also found by Hargittai and Shafer (2006), who reported that adolescent boys showed higher levels of confidence in the use of technology. In contrast, Item 15—which demands reflection on social experiences in a digital context—favours female students more. These findings are in line with the study of Spacks (2022), which identified that female students are better able to express interpersonal and emotional responses in the form of narrative writing.

However, this difference does not necessarily indicate that the instrument is biased overall. On the contrary, these results indicate that the content of the context and the type of cognitive demands in the question items can affect student performance based on social characteristics such as gender. These findings confirm the importance of content validation in the preparation of digital literacy instruments. To ensure a fair and inclusive instrument, question developers need to:

1. Involve a panel of cross-gender experts in the process of writing and reviewing questions;
2. Conduct systematic DIF tests during the instrument validation process;
3. Structure questions with a neutral context or include diverse socio-cultural representations.

This approach is in line with the principles of Universal Design for Learning (UDL), which emphasizes accessibility, diversity of expression, and inclusion in the learning process. The analysis of DIF in this study shows that although most items are neutral, there are several question items that have the potential to benefit certain groups. This confirms that fairness validity must be an integral part of digital literacy assessments — especially in the context of education that is increasingly multicultural and equity-based.

4.3. Digital Reading Ability Mapping (Item-Person Map)

One of the basic principles in Item Response Theory (IRT)-based assessment is an understanding of how well the items in an instrument measure the range of abilities possessed by test takers. To review this, a visual tool known as the Item-Person Map or Wright Map is used. The Wright Map presents two main elements on a single continuum line: the distribution of students' abilities and the difficulty level of the item. The vertical axis depicts a logite scale that measures ability and difficulty in equivalent units, thus allowing for a direct comparison between "people" and "question items". To evaluate the alignment between student abilities and item difficulties, a Rasch-based Wright Map was used. Figure 3 presents this distribution on a logit scale.

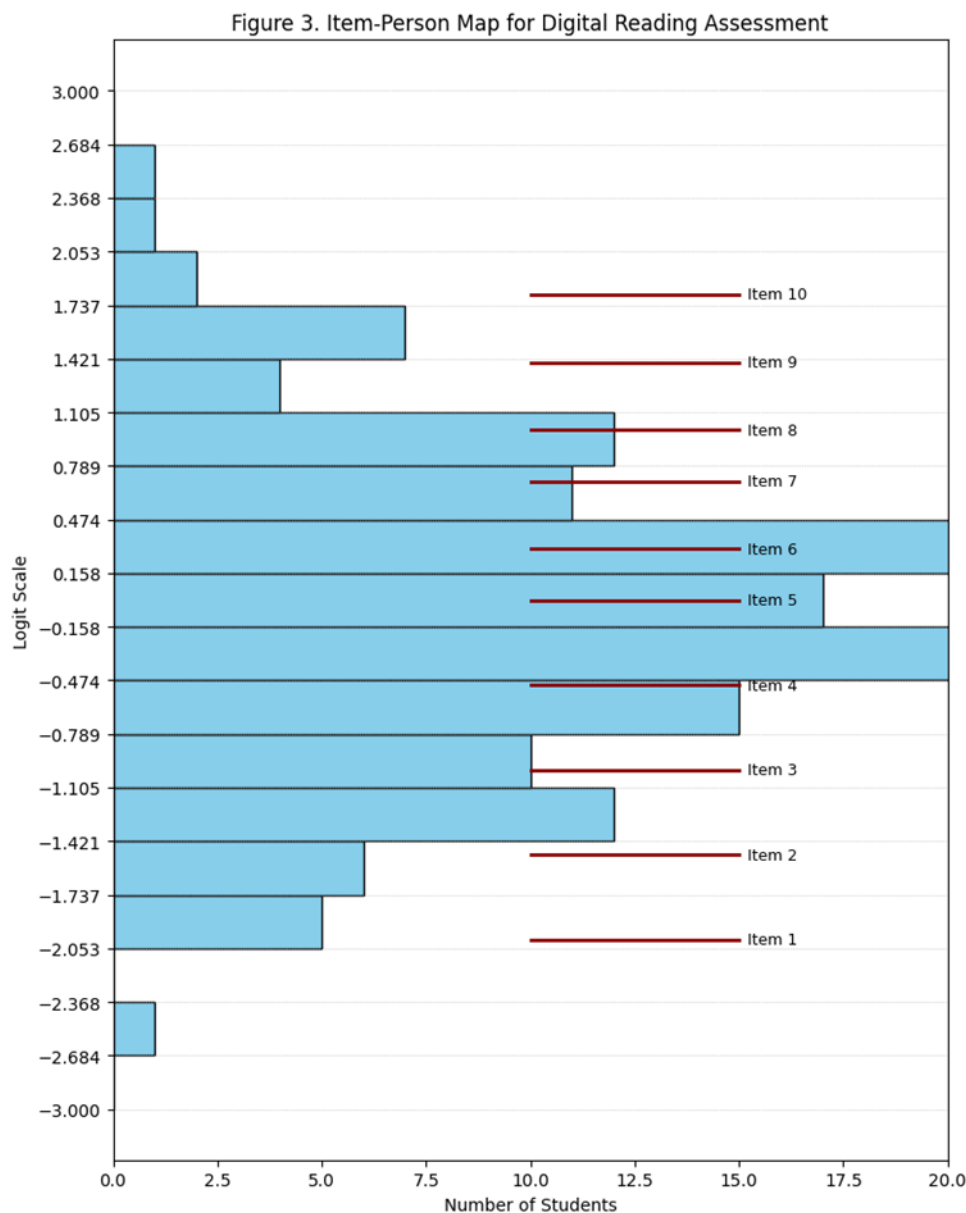


Figure 3. Item-Person Map for Digital Reading Assessment

Caption: The dots on the left side represent the distribution of students based on digital reading ability. The dots on the right side indicate the difficulty level of each item.

Figure 3 shows that the majority of students are in the mid-to-lower ability range, with the highest concentrations ranging from -1.5 to +0.5. Most of the question items are grouped in a relatively easy to moderate difficulty range, while only two items are located in a logit range above +1.0 — indicating a higher level of difficulty. This condition shows that although the instrument has covered variations in difficulty levels, there are still gaps in the area of high ability, which makes the superior students not sufficiently challenged. In contrast, there was a significant overlap between items and student distributions in the middle range, indicating that most of the questions did not sufficiently differentiate abilities in a granular manner. In the framework of IRT, the optimal instrument is one that has an even distribution of items and is proportional to the distribution of participants' abilities. In this context, digital reading instruments show limitations in reaching the end of the spectrum, both for the highest and lowest categories.

These findings have several practical implications:

- First, for students with high abilities, this instrument has not been able to stimulate advanced thinking skills such as evaluation of digital sources, interpretation of multimodal texts, or analysis of ideas in a social context.
- Second, the development of future items needs to include question items with a more complex structure and content, such as questions that require the interpretation of interactive graphs, information credibility assessments, or critical literacy-based decision-making.

In addition, the distribution of students' abilities that tend to be concentrated in the lower range also reflects the digital literacy learning gap in the classroom. This indicates the need for a more adaptive and differential learning strategy so that each student gets a challenge that matches his or her cognitive potential.

Overall, the Wright Map provides a visual mapping that is very useful for evaluating the extent to which the instrument is able to assess a wide range of students' ability levels. In this study, there is a gap between the scope of instruments and the diversity of students' abilities, which demands further development both in terms of question design and pedagogical approaches. Strengthening the instrument at the extreme points of the logit scale is essential for digital literacy assessments to function not only as a measuring tool, but also as a diagnostic tool for more targeted learning interventions.

4.4. Digital Literacy Strategy Pattern (Heatmap Analysis)

Digital literacy not only includes understanding the content of the text, but also touches on strategic aspects in the process of compiling and conveying messages through digital media. In this context, students' writing strategies in the digital environment can be reflected in the use of typical features of digital text, such as headings/subheadings, hyperlinks, personal opinions, and visual elements such as emojis. To systematically review this aspect, an analysis of the frequency of use of these four main features in student writing from each writing style cluster was conducted. The results are visualized in heatmap form, as shown in Figure 4.

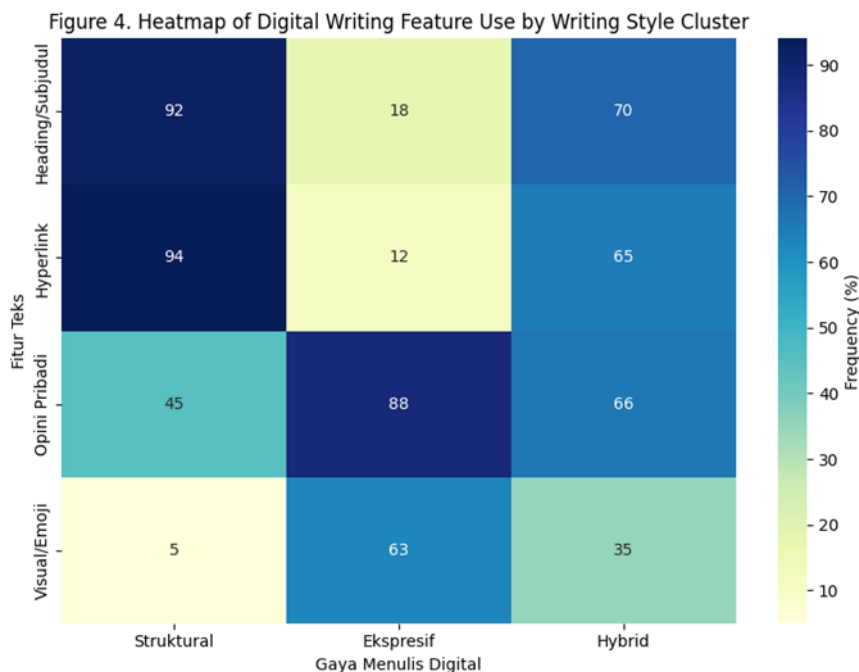


Figure 4. Heatmap of Digital Writing Feature Use by Writing Style Cluster

Description: Darker colors indicate a higher frequency of feature usage in that group.

As a complement, Table 3 presents the frequency value in the form of a percentage so that it can be compared quantitatively.

Table 3. Frequency of Digital Text Features by Writing Style Cluster (%)

	Fitur Teks	Structure	Expressive	Hybrid
Headings/Subheadings	92%	18%		70%
Hyperlink	94%	12%		65%
Personal Opinion	45%	88%		66%
Visual/Emoji	5%	63%		35%

Figure 4 and Table 3 show the pattern of feature usage that differs greatly between writing style clusters. Students in the Structural cluster were very dominant in the use of headings and hyperlinks (above 90% each), but almost no use of visual elements (5%) and personal opinions (45%). It shows a preference for a formal, informative, and technical approach, in accordance with academic or professional writing conventions. In contrast, Expressive groups tend to avoid technical structures and features, and use more narrative and emotional expression. The high use of personal opinions (88%) and emojis (63%) reflects a preference for communicative and personal writing styles. However, this approach risks ignoring aspects of digital formality and structure that are important in an academic or professional context.

The Hybrid group again showed balance. They still use headings (70%) and hyperlinks (65%) to support readability and credibility, but also insert personal and visual opinions to reinforce the appeal of the message. It reflects a high level of communication adaptability according to the purpose, audience, and context of the writing. These findings emphasize that digital literacy competence is not only a matter of technical mastery but also of contextual communication strategies. Students' writing styles appear to be a reflection of their literacy identity, which in turn will affect the effectiveness of message delivery in various digital contexts. From a pedagogical perspective, teachers and curriculum developers can leverage these findings to:

1. Compiling feature-based digital writing rubrics, not just conventional content or structures;
2. Provide more personalized feedback, for example highlighting the strength of students' expressive styles but also encouraging the use of more formal structures;
3. Design adaptive digital writing training, such as themed assignments, blended style challenges, or revision practices based on each student's style profile.

This heatmap analysis reinforces previous findings that students with Hybrid styles not only excel in digital literacy scores, but also have high flexibility in the utilization of digital text features. This means that the ideal digital literacy competency is not only seen from the number of features used, but also from how appropriate and strategic its use is in the context of diverse digital communication.

The finding that hybrid writers demonstrated the highest digital literacy performance aligns with previous studies emphasizing the importance of adaptability in digital communication (Julien, 2018; Sharma et al., 2016). These students' ability to balance structural coherence with expressive content reflects what Belshaw and Higgins (2011) define as "digitally mature writers"—those capable of navigating multiple communicative demands effectively. In addition, the DIF results confirming gender-based item bias echo earlier work by Hargittai & Shafer (2006), highlighting how social factors shape students' digital confidence and performance. Similarly, the observed gap in assessment coverage in the Wright Map is consistent with critiques by Timmis et al. (2016) regarding traditional

assessments' inability to capture upper-range digital competencies. By integrating these insights, the current study extends the literature by offering an empirical framework that connects writing style, assessment fairness, and multimodal communication strategies in a single model applicable to primary education.

Overall, the results of this study highlight that students' digital writing styles are not merely surface-level preferences, but reflect deeper cognitive and communicative competencies. The dominance of the Hybrid cluster underscores the value of flexible, audience-aware, and feature-rich communication strategies in achieving high digital literacy performance. These insights support a move away from one-size-fits-all assessments and toward differentiated, identity-sensitive literacy instruction. From a practical standpoint, educators are encouraged to recognize and build upon students' natural writing tendencies—whether structural, expressive, or hybrid—through tailored feedback, inclusive assessment instruments, and multimodal writing tasks. Developing students' awareness of their digital literacy identity can foster more meaningful engagement with digital texts and strengthen their readiness for communication in varied real-world contexts. These findings have important implications for educational outcomes. The differences in digital writing styles and feature usage are not merely stylistic; they correlate with students' ability to communicate, interpret information, and demonstrate critical thinking in digital environments—skills that are increasingly recognized as essential components of 21st-century education. As such, recognizing and supporting diverse writing profiles can lead to more equitable and effective literacy instruction and assessment practices that directly impact students' academic success and digital readiness.

6. Conclusion

This research highlights the importance of understanding students' digital literacy as a complex form of competence, not only including understanding the content of the text but also the strategic ability to write, choose digital features, and convey messages effectively in an online context. Through a quantitative-visual approach based on PCA, DIF, Wright Map, and heatmap analysis, it was found that students adopted three main digital writing styles—Structural, Expressive, and Hybrid—each of which had a tendency to use features, appropriate difficulty levels, and different literacy outcomes. The Hybrid cluster has consistently shown excellence in terms of flexibility and effectiveness of digital communication, while recording the highest literacy scores. On the other hand, the DIF analysis revealed the potential for gender inequality in response to some items, while the Wright Map showed that most items did not adequately reach students with extreme abilities, particularly in the high category. Analysis of text features through heatmaps also showed that students' writing styles are not just technical variations, but rather reflect their evolving literacy identities in the digital ecosystem.

These findings have important implications for the world of education, especially in designing digital literacy learning that is more contextual, equitable, and adaptive. Writing style mapping can be used as a basis for providing personal feedback, compiling more relevant rubrics, and developing assessment instruments that are sensitive to diversity of abilities and social backgrounds. In the midst of the accelerating flow of digital transformation, digital literacy competencies are not enough to be approached with a single standard; rather, they require an understanding of the diversity of communication strategies used by students in various contexts. Thus, this article asserts that writing skills in the digital space are a form of strategic literacy that reflects not only technical mastery, but also a way of thinking, communicating, and participating critically in an interconnected world.

7. Limitations

This study is subject to several limitations. First, the sample was limited to 150 elementary school students from urban public schools in Indonesia, which may affect the generalizability of findings to other educational levels or contexts. Second, the digital writing tasks were conducted using a single

online platform with a predefined interface, which may have constrained students' creative expression or familiarity with tools. Only open-ended informational texts were used as writing prompts, potentially limiting the variety of genre-specific strategies. Additionally, students' prior experience with digital tools or typing skills was not systematically controlled, which might have influenced both the length and complexity of their writing. Future research should explore a broader sample across diverse schools and include comparative analysis across digital platforms and writing genres to validate and expand the present findings.

8. Suggestion

Based on the findings of this study, it is suggested that the development of digital literacy learning and assessment in schools be carried out more adaptively, taking into account the diverse profiles of students' writing styles. Teachers need to be encouraged to integrate data-driven approaches such as clustering of writing styles and analysis of text features in reflection and feedback practices. In addition, instrument developers should pay attention to the aspect of fairness validity and ensure that the question items cover a balanced spectrum of difficulty, so as to be able to measure students' abilities representatively. Further research is recommended to explore the relationship between digital writing styles and other literacy dimensions, such as visual, collaborative, or digital ethics literacy, as well as to expand the study context to different levels and educational regions to enrich the generalization of findings.

Declarations

Author Contributions. Wahyu Dini Septiari: Conceptualization, Methodology, Software, Writing-Original draft preparation; Sarwiji Suwandi: Data curation, Writing-Original draft preparation, Software, Validation; Andayani: Visualization, Investigation, WWriting–Reviewand Editing.

Conflicts of Interest. The authors declare no conflict of interest.

Funding. Thanks to the Universitas Veteran Bangun Nusantara, Indonesia for fully supporting this research.

Acknowledgements. We thank the Universitas Veteran Bangun Nusantara and Universitas Sebelas Maret for supporting this research.

References

- Adiprasetyo, J. (2022). The Development of Communication Research in Indonesia in 2001-2020. *Jurnal Kajian Komunikasi*, 10(1), 105–120.
- Afnan, A. (2023). *Digital Literacies for English Language Learners: A Multimodal Social Semiotic Approach to Investigate Saudi Students' Reading of English Tweets*. Retrieved from [http://theses.ncl.ac.uk/jspui/handle/10443/5908%0Ahttps://theses.ncl.ac.uk/jspui/bitstream/10443/5908/1/Alaloula Afnan 150575649 Final Submission ecopy.pdf](http://theses.ncl.ac.uk/jspui/handle/10443/5908%0Ahttps://theses.ncl.ac.uk/jspui/bitstream/10443/5908/1/Alaloula%20Afnan%20150575649%20Final%20Submission%20ecopy.pdf)
- Anderson, J., Rainie, L., & Luchsinger, A. (2018). Artificial intelligence and the future of humans. *Pew Research Center*, 10(12).
- Arono, Arsyad, S., Syahrman, Nadrah, & Villia, A. S. (2022). Exploring the effect of digital literacy skill and learning style of students on their meta-cognitive strategies in listening. *International Journal of Instruction*, 15(1), 527–546. <https://doi.org/10.29333/iji.2022.15130a>
- Bakhtiar, M. J., & Behzadi, M. (2023). Digital Storytelling: Unleashing the Power of Narrative in the Digital Age. *The Second International Conference on Industrial Marketing*. Retrieved from <https://www.researchgate.net/publication/372133782>
- Beardsley, M., Albó, L., Aragón, P., & Hernández-Leo, D. (2021). Emergency education effects on teacher abilities and motivation to use digital technologies. *British Journal of Educational*

Technology, 52(4), 1455–1477. <https://doi.org/10.1111/bjet.13101>

- Belshaw, D., & Higgins, S. (2011). Digital literacy, digital natives, and the continuum of ambiguity. *Dougbelshaw. Com*, (1930), 1–11. Retrieved from <https://doubelshaw.com/ambiguity/>
- Berge, K. L., Evensen, L. S., & Thygesen, R. (2016). The Wheel of Writing: a model of the writing domain for the teaching and assessing of writing as a key competency. *Curriculum Journal*, 27(2), 172–189. <https://doi.org/10.1080/09585176.2015.1129980>
- Castagna, F., Centobelli, P., Cerchione, R., Esposito, E., Oropallo, E., & Passaro, R. (2020). Customer knowledge management in SMEs facing digital transformation. *Sustainability (Switzerland)*, 12(9), 3899. <https://doi.org/10.3390/su12093899>
- Changwong, K., Sukkamart, A., & Sisan, B. (2018). Critical thinking skill development: Analysis of a new learning management model for Thai high schools. *Journal of International Studies*, 11(2).
- Cooke, N. A. (2017). Posttruth, truthiness, and alternative facts: Information behavior and critical information consumption for a new age. *Library Quarterly*, 87(3), 211–221. <https://doi.org/10.1086/692298>
- Costa, P. J. B. M. (2023). *Multimodal Digital Literacy Practices: Perspectives of L2 Academic Writing Instructors*. Retrieved from <https://scholarcommons.sc.edu/etd/7485/%0Ahttps://scholarcommons.sc.edu/cgi/viewcontent.cgi?article=8299&context=etd>
- Dahlström, H. (2022). Students as digital multimodal text designers: A study of resources, affordances, and experiences. *British Journal of Educational Technology*, 53(2), 391–407.
- Daniel, R., Stephen, L., Brendan, W., & Jennette, L. (2023). Analyzing Media Messages Using Quantitative Content Analysis in Research, Fifth Edition. In *Analyzing Media Messages Using Quantitative Content Analysis in Research, Fifth Edition*. <https://doi.org/10.4324/9781003288428>
- Danielsson, K., & Selander, S. (2016). Reading Multimodal Texts for Learning – a Model for Cultivating Multimodal Literacy. *Designs for Learning*, 8(1), 25–36. <https://doi.org/10.16993/dfl.72>
- De Ayala, R. J. (2018). Item Response Theory and Rasch Modeling. In *The Reviewer's Guide to Quantitative Methods in the Social Sciences: Second Edition* (pp. 145–163). <https://doi.org/10.4324/9781315755649-11>
- Drucker, A. M., Fleming, P., & Chan, A. W. (2016). Research Techniques Made Simple: Assessing Risk of Bias in Systematic Reviews. *Journal of Investigative Dermatology*, Vol. 136, pp. e109–e114. <https://doi.org/10.1016/j.jid.2016.08.021>
- E.Goldberg, D., & Scheiner, S. M. (2023). ANOVA and ANCOVA: Field Competition Experiments. In *Design and Analysis of Ecological Experiments* (pp. 77–98). <https://doi.org/10.1093/oso/9780195131871.003.0005>
- Giri, V. N. (2006). Culture and Communication Style. *Review of Communication*, 6(1–2), 124–130. <https://doi.org/10.1080/15358590600763391>
- Gobster, P. H., & Rickenbach, M. G. (2004). Private forestland parcelization and development in Wisconsin's Northwoods: Perceptions of resource-oriented stakeholders. *Landscape and Urban Planning*. USDA Forest Service, N. Central Research Station-Chicago, 1033 University Pl., Evanston, IL 60201, United States.
- Haasler, M., Maier, T. M., Grotjahn, R., Gückel, S., Arbuznikov, A. V., & Kaupp, M. (2020). A Local Hybrid Functional with Wide Applicability and Good Balance between (De)Localization and Left-Right

- Correlation. *Journal of Chemical Theory and Computation*, 16(9), 5645–5657. <https://doi.org/10.1021/acs.jctc.0c00498>
- Hanelt, A., Bohnsack, R., Marz, D., & Antunes Marante, C. (2021). A Systematic Review of the Literature on Digital Transformation: Insights and Implications for Strategy and Organizational Change. *Journal of Management Studies*, 58(5), 1159–1197. <https://doi.org/10.1111/joms.12639>
- Hargittai, E., & Shafer, S. (2006). Differences in actual and perceived online skills: The role of gender. *Social Science Quarterly*, 87(2), 432–448. <https://doi.org/10.1111/j.1540-6237.2006.00389.x>
- Iordache, C., Mariën, I., & Baelden, D. (2017). Developing Digital Skills and Competences: A Quick-Scan Analysis of 13 Digital Literacy Models. *Italian Journal of Sociology of Education*, 9(Italian Journal of Sociology of Education 9/1), 6–30.
- Ippolito, D., Yuan, A., Coenen, A., & Burnam, S. (2022). Creative Writing with an AI-Powered Writing Assistant: Perspectives from Professional Writers. *ArXiv Preprint ArXiv:2211.05030*. Retrieved from <http://arxiv.org/abs/2211.05030>
- Järvi, K., Almpantopoulou, A., & Ritala, P. (2018). Organization of knowledge ecosystems: Prefigurative and partial forms. *Research Policy*, 47(8), 1523–1537. <https://doi.org/10.1016/j.respol.2018.05.007>
- Jayanti, A. D. (2019). Students' writing ability on english descriptive text at grade viii in smpn 33 padang. *ENGLISH FRANCA : Academic Journal of English Language and Education*, 3(01), 71. <https://doi.org/10.29240/ef.v3i01.843>
- Julien, H. (2018). Digital Literacy in Theory and Practice. In *Encyclopedia of Information Science and Technology, Fourth Edition* (pp. 22–32). <https://doi.org/10.4018/978-1-5225-7659-4.ch003>
- Kapan, R., & GÜREL, T. Y. (2022). An Evaluation of the Environmental Literacy Levels of Nursing Students in Turkey. *Health Sciences Quarterly*, 2(3), 139–148. <https://doi.org/10.26900/hsq.2.3.03>
- Kennedy, C. J., Bacon, G., Sahn, A., & von Vacano, C. (2020). Constructing interval variables via faceted Rasch measurement and multitask deep learning: a hate speech application. *ArXiv Preprint ArXiv:2009.10277*. Retrieved from <http://arxiv.org/abs/2009.10277>
- Kim, E.-S., Kang, W. Y., On, K.-W., Heo, Y.-J., & Zhang, B.-T. (2020). Hypergraph Attention Networks for Multimodal Learning. *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition*, 14581–14590.
- Klein Buller, M., & Buller, D. B. (1987). Physicians' communication style and patient satisfaction. *Journal of Health and Social Behavior*, 28(4), 375–388. <https://doi.org/10.2307/2136791>
- Krippendorff, K. (2018). *Content analysis: An introduction to its methodology*. Sage publications.
- Kustini, S., Suherdi, D., & Musthafa, B. (2020). Beyond traditional literacies: A multimodal-based instruction to fostering student digital literacy learning. *Jurnal Pendidikan Bahasa Dan Sastra*, 20(1), 37–47. https://doi.org/10.17509/bs_jpbsp.v20i1.25969
- Leaning, M. (2019). An approach to digital literacy through the integration of media and information literacy. *Media and Communication*, 7(2 Critical Perspectives), 4–13. <https://doi.org/10.17645/mac.v7i2.1931>
- Li, L., Johnson, J., Aarhus, W., & Shah, D. (2022). Key Factors in MOOC Pedagogy Based on NLP Sentiment Analysis of Learner Reviews: What Makes a Hit. *Computers & Education*, 176, 104354.

- Madani, H. (2016). Assessment of Reading Comprehension. *Revista Românească Pentru Educație Multidimensională*, 8(1), 125–147.
- Marín, V. I., & Castañeda, L. (2023). Developing Digital Literacy for Teaching and Learning. In *Handbook of Open, Distance and Digital Education* (pp. 1089–1108). https://doi.org/10.1007/978-981-19-2080-6_64
- Martínez-Bravo, M. C., Chalezquer, C. S., & Serrano-Puche, J. (2022). Dimensions of Digital Literacy in the 21st Century Competency Frameworks. *Sustainability (Switzerland)*, 14(3), 1867. <https://doi.org/10.3390/su14031867>
- Michalovich, A. (2023). The Social Drama of Digital Multimodal Composing: A Case Study With Emergent Bi/Multilingual Newcomer Students. *Journal of Adolescent and Adult Literacy*, 66(6), 334–343. <https://doi.org/10.1002/jaal.1286>
- Mills, K. A. (2015). *Literacy Theories for The Digital Age: Social, Critical, Multimodal, Spatial, Material and Sensory Lenses* (Vol. 45). Multilingual Matters.
- Nabhan, S., & Habók, A. (2025). The Digital Literacy Academic Writing Scale: Exploratory Factor Analysis. *SAGE Open*, 15(1), 21582440241311708. <https://doi.org/10.1177/21582440241311709>
- Nguyen, L. A. T., & Habók, A. (2024). Tools for assessing teacher digital literacy: a review. *Journal of Computers in Education*, 11(1), 305–346. <https://doi.org/10.1007/s40692-022-00257-5>
- Normile, I. H. (2025). A Model for Understanding and Expanding the Scope of Critical Thinking. *Studies in Philosophy and Education*. <https://doi.org/10.1007/s11217-024-09976-x>
- Olivetti, E. A., Cole, J. M., Kim, E., Kononova, O., Ceder, G., Han, T. Y. J., & Hiszpanski, A. M. (2020). Data-driven materials research enabled by natural language processing and information extraction. *Applied Physics Reviews*, Vol. 7. <https://doi.org/10.1063/5.0021106>
- Passey, D., Shonfeld, M., Appleby, L., Judge, M., Saito, T., & Smits, A. (2018). Digital Agency: Empowering Equity in and through Education. *Technology, Knowledge and Learning*, 23(3), 425–439. <https://doi.org/10.1007/s10758-018-9384-x>
- Pera, R., Occhiocupo, N., & Clarke, J. (2016). Motives and resources for value co-creation in a multi-stakeholder ecosystem: A managerial perspective. *Journal of Business Research*, 69(10), 4033–4041. <https://doi.org/10.1016/j.jbusres.2016.03.047>
- Sharma, R., Fantin, A. R., Prabhu, N., Guan, C., & Dattakumar, A. (2016). Digital literacy and knowledge societies: A grounded theory investigation of sustainable development. *Telecommunications Policy*, 40(7), 628–643. <https://doi.org/10.1016/j.telpol.2016.05.003>
- Singh, J., Tugwell, P., Wells, G., Vecchi, S., Davies, P., Churchill, R., & Reeves, B. (2018). ROBIS: A new tool to assess risk of bias in systematic reviews was developed. *Recenti Progressi in Medicina*, Vol. 109, pp. 421–431. Elsevier.
- Spacks, P. M. (2022). THE FEMALE IMAGINATION: A Literary and Psychological Investigation of Women’s Writing. In *The Female Imagination: A Literary and Psychological Investigation of Women’s Writing*. <https://doi.org/10.4324/9781003287964>
- Spante, M., Hashemi, S. S., Lundin, M., & Algers, A. (2018). Digital competence and digital literacy in higher education research: Systematic review of concept use. *Cogent Education*, Vol. 5, pp. 1–21. <https://doi.org/10.1080/2331186X.2018.1519143>
- Sparks, J. R., Katz, I. R., & Beile, P. M. (2016). Assessing Digital Information Literacy in Higher Education: A Review of Existing Frameworks and Assessments With Recommendations for

- Next-Generation Assessment. *ETS Research Report Series*, 2016(2), 1–33. <https://doi.org/10.1002/ets2.12118>
- Tarkhova, L., Tarkhov, S., Nafikov, M., Akhmetyanov, I., Gusev, D., & Akhmarov, R. (2020). Infographics and their application in the educational process. *International Journal of Emerging Technologies in Learning*, 15(13), 63–80. <https://doi.org/10.3991/ijet.v15i13.14647>
- Timmis, S., Broadfoot, P., Sutherland, R., & Oldfield, A. (2016). Rethinking Assessment in a Digital Age: Opportunities, Challenges and Risks. *British Educational Research Journal*, 42(3), 454–476.
- Turnbull, D., Chugh, R., & Luck, J. (2023). Systematic-narrative hybrid literature review: A strategy for integrating a concise methodology into a manuscript. *Social Sciences and Humanities Open*, 7(1), 100381. <https://doi.org/10.1016/j.ssaho.2022.100381>
- Ukanda, F., Othuon, L., Agak, J., & Oleche, P. (2024). Effectiveness of Mantel-Haenszel And Logistic Regression Statistics in Detecting Differential Item Functioning Under Different Conditions of Sample Size, Ability Distribution and Test Length. *American Journal of Educational Research*, 7(11), 878–887. Retrieved from <http://pubs.sciepub.com/>
- Wandasari, Y., Kristiawan, M., & Arafat, Y. (2019). Policy Evaluation of School's Literacy Movement on Improving Discipline of State High School Students. *International Journal of Scientific & Technology Research*, 8(4), 190–198.
- Wechsler, S. M., Saiz, C., Rivas, S. F., Vendramini, C. M. M., Almeida, L. S., Mundim, M. C., & Franco, A. (2018). Creative and Critical Thinking: Independent or Overlapping Components? *Thinking Skills and Creativity*, 27, 114–122.
- Wiesinger, S., & Beliveau, R. (2016). *Digital literacy : a primer on media, identity, and the evolution of technology*. Peter Lang New York.
- Willinsky, J. (2017). The new literacy: Redefining reading and writing in the schools. In *The New Literacy: Redefining Reading and Writing in the Schools*. <https://doi.org/10.4324/9781351235945>
- Yamaç, A., Öztürk, E., & Mutlu, N. (2020). Effect of digital writing instruction with tablets on primary school students' writing performance and writing knowledge. *Computers and Education*, 157, 103981. <https://doi.org/10.1016/j.compedu.2020.103981>
- Yang, H. (2024). From digital literacy to digital competence: The structure of Teacher Digital Competence (TDC). *Innovations in Education and Teaching International*, 68(5), 2449–2472. <https://doi.org/10.1080/14703297.2024.2437675>
- Zubareva, S. (2020). Socio-cultural Identity of the Digital Generation in the 21st Century: Cultural and Philosophical Analysis. In *Lecture Notes in Networks and Systems* (Vol. 131, pp. 960–968). https://doi.org/10.1007/978-3-030-47415-7_103

About the Contributor(s)

Wahyu Dini Septiari, Indonesian Language and Literature Education Study Program, Faculty of Teacher Training and Education, Universitas Sebelas Maret, Indonesia
Email: wahyudiniseptiari.18@gmail.com

Sarwiji Suwandi, Indonesian Language and Literature Education Study Program, Faculty of Teacher Training and Education, Universitas Sebelas Maret, Indonesia
Email: sarwijiswan@staff.uns.ac.id

Andayani, Indonesian Language and Literature Education Study Program, Faculty of Teacher Training and Education, Universitas Sebelas Maret, Indonesia

Email: andayani@staff.uns.ac.id

Publisher's Note: *The opinions, statements, and data presented in all publications are solely those of the individual author(s) and contributors and do not reflect the views of Universitepark, EDUPIJ, and/or the editor(s). Universitepark, the Journal, and/or the editor(s) accept no responsibility for any harm or damage to persons or property arising from the use of ideas, methods, instructions, or products mentioned in the content.*
