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Profiling Digital Health Literacy in Virus-Focused Biology Learning among Indonesian Senior High School Students

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Abstract

This study profiled digital health literacy (DHL) among senior high school students in virus-focused biology learning and examined whether total DHL scores differed by gender. A quantitative descriptive survey was conducted with 64 Grade 12 students from two classes at a public senior high school in Malang, East Java, Indonesia. Participants were selected through convenience sampling. DHL was measured using an Indonesian adaptation of the Digital Health Literacy Instrument. The instrument comprised 12 items across four dimensions—Information Searching, Self-Generated Content, Evaluating Reliability, and Determining Relevance—rated on a five-point Likert scale. The overall internal consistency of the adapted instrument in the main sample was $\alpha = 0.659$. Data were analyzed using descriptive statistics, an independent-samples t-test, effect-size estimation, and a Mann–Whitney U sensitivity analysis. Based on the study-specific descriptive thresholds, students' overall DHL was predominantly classified as problematic ($M = 41.20$, $SD = 6.69$): 17.19% were classified as inadequate, 70.31% as problematic, and 12.50% as sufficient. Information Searching had the highest mean score, whereas Evaluating Reliability had the lowest. No statistically significant difference was found between male and female students, $t(62) = 0.051$, $p = 0.959$, with a negligible effect size (Cohen's $d = 0.013$). These findings indicate that students perceived greater ease in locating digital health information than in evaluating its credibility and evidentiary quality. Virus-focused biology instruction should therefore provide explicit opportunities for source evaluation, cross-source verification, and evidence-based interpretation of digital health information.

Keywords: Digital Health Literacy; Biology Education; Senior High School Students; Virus-Related Information; Source Evaluation

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INTRODUCTION

Over the past two decades, digital technology has transformed how health information is produced, disseminated, and accessed. Websites, search engines, health applications, and social media now enable adolescents to obtain information about health-related biological topics, including viruses, vaccination, and infectious-disease prevention. However, extensive access to digital information also creates challenges because users must select relevant content, verify its accuracy, and evaluate the credibility of its sources. In Indonesia, internet penetration among adolescents has reached 98.20% (APJII, 2023), whereas broader literacy and information-processing outcomes remain concerning, as reflected in the PISA 2022 results (OECD, 2023). This disparity suggests that extensive digital exposure does not necessarily correspond to strong critical-information skills. Consequently, the digital health literacy of senior high school students, particularly their ability to evaluate virus-related information within biology learning, requires closer examination.

This need has become increasingly important because health misinformation and infodemics spread rapidly through digital environments and are often difficult to distinguish from scientifically supported information (Cuan-Baltazar et al., 2020; Okan et al., 2023). Misleading claims concerning virus-related infectious diseases, including COVID-19 and influenza, as well as vaccination, have circulated widely through social media and may influence public understanding and health-related behavior (Tümer & Sümen, 2022; Duplaga, 2020). These conditions emphasize the importance of Digital Health Literacy (DHL), defined as the ability to search for, understand, evaluate, and use health information obtained from digital sources effectively (Van Der Vaart & Drossaert, 2017; Bekesy, 2022). DHL is increasingly recognized as an important determinant of health because it influences an individual's capacity to make informed, safe, and evidence-based health decisions (Sørensen et al., 2012; López et al., 2023).

Adolescents are among the most intensive internet users and frequently use digital platforms to obtain health information (Fitzpatrick, 2023; Nguyen et al., 2021). Although they may express confidence in their ability to search for information, studies indicate that many adolescents experience difficulty evaluating source credibility and interpreting scientific content (Dadaczynski et al., 2021; Stauch et al., 2025). They may also rely on social media, peer opinions, or familiar online content rather than information produced by qualified experts or scientific institutions (Santos et al., 2017; Ahlborg et al., 2023). These information-use patterns may increase their vulnerability to misleading claims concerning virus mutations, vaccine effectiveness, and disease-transmission mechanisms. Strengthening DHL among adolescents therefore requires more than technical competence in accessing digital information; it also requires the cognitive and epistemic capacity to evaluate evidence, reason scientifically, and connect information with established knowledge (Čavojová et al., 2022; Drummond Otten & Fischhoff, 2023).

Biology learning offers a relevant educational context for developing these capacities. Biological topics such as virology, immune responses, and infectious diseases enable students to connect digital health information with scientific concepts encountered in the curriculum (Wolf et al., 2012; Subiantoro et al., 2021; Farooq et al., 2024). Biology education also emphasizes scientific reasoning, data interpretation, and evidence evaluation, which are conceptually relevant to DHL. Evidence-based and inquiry-oriented learning approaches may strengthen students' critical-thinking skills and their ability to examine the validity of scientific claims (Kurniaty et al., 2024). Nevertheless, the integration of digital-information evaluation into biology learning in Indonesian secondary schools remains limited. Biology instruction may emphasize conceptual knowledge and content recall without systematically engaging students in evaluating digital claims related to biological and health issues (Subiantoro et al., 2021; Jewarut & Sumarni, 2022). Students may therefore be able to describe viruses using textbook information while still experiencing difficulty judging the credibility of online claims about viral mutations or vaccine effectiveness.

Research on DHL among adolescents has expanded across different countries (Sakellari et al., 2024; Liu et al., 2024; Renninger et al., 2024). However, much of this research has focused on university students or general populations, whereas relatively few studies have examined senior high school students within biology-education settings. Research on DHL among Indonesian high school students also remains limited despite the growing challenges associated with digital misinformation and online health-information use (Hasanatuludhhiyah et al., 2024; Sjamssuddin et al., 2024). Moreover, few studies have examined DHL in relation to specific biological topics such as viruses, even though virus-related claims are highly visible in contemporary digital environments. Consequently, limited evidence is available regarding the strengths and weaknesses of each DHL dimension among senior high school students when they engage with virus-related digital information.

The present study addresses this gap by positioning DHL assessment as a context-specific needs assessment within senior high school biology education. Rather than focusing only on an overall DHL score, the study profiles four dimensions—Information Searching, Self-Generated Content, Evaluating Reliability, and Determining Relevance—to identify students' relative strengths and areas requiring instructional support. These dimensions are conceptually associated with scientific reasoning and evidence evaluation, although the present study does not directly measure those constructs. By focusing on virus-related information, the study provides empirical evidence that may inform the development of biology instruction that responds more directly to the challenges of digital health misinformation.

Figure 1 presents the conceptual relationship between the four DHL dimensions, relevant biology-learning processes, and potential classroom outcomes. The framework positions information searching, digital scientific communication, reliability evaluation, and relevance determination as skills that may be developed through inquiry, evidence analysis, source verification, and scientific communication activities. The expected outcomes shown in the framework are conceptual instructional outcomes; the present study directly assesses only students' self-reported DHL dimensions.

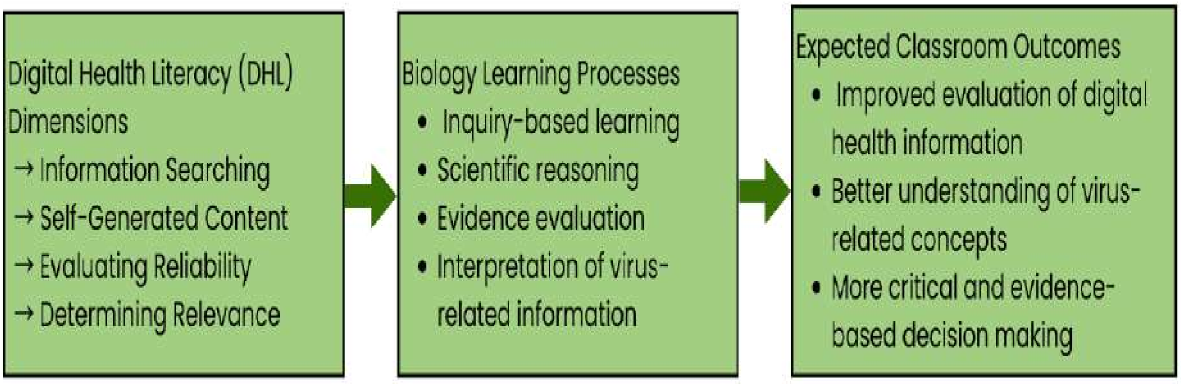

Figure 1. Conceptual framework linking digital health literacy dimensions with biology-learning processes and expected classroom outcomes

Based on these considerations, this study aimed to: (1) describe the achievement profile of each DHL dimension among senior high school students in the context of virus-focused biology learning and (2) examine whether total DHL scores differed by gender. Because the study used self-reported data from a single school, its findings are positioned as a contextual profile intended to inform the development of more responsive biology-learning practices rather than as population-level estimates.

METHOD

Research Design

This study employed a quantitative descriptive survey design to profile students' Digital Health Literacy (DHL) in the context of biology learning, particularly on virus-related topics. The descriptive design was selected because the study focused on documenting students' perceived abilities to search for, communicate, evaluate, and determine the relevance of digital health information without manipulating the learning environment or study variables.

In addition to describing the overall and dimension-specific DHL profiles, the study examined whether DHL scores differed between male and female students. Data were collected using an adapted DHL questionnaire and analyzed through descriptive statistics, study-specific score categorization, assumption testing, an independent-samples t-test, effect-size estimation, and a nonparametric sensitivity analysis. Figure 2 summarizes the research process, including instrument adaptation, pilot testing, main data collection, and statistical analysis.

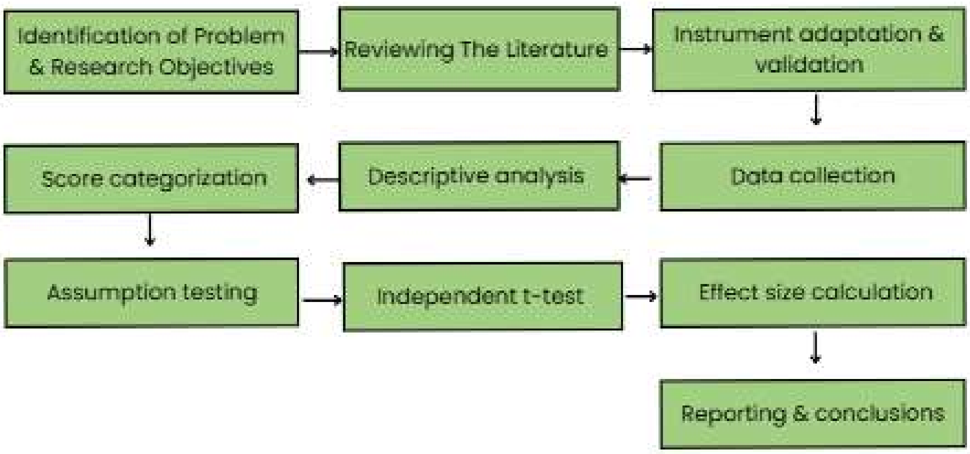

Figure 2. Research flowchart

Participants

The main study was conducted at a public senior high school in Malang, East Java, Indonesia. The identity of the participating school is withheld to protect institutional and participant confidentiality. The target population comprised Grade 12 students enrolled at the school during the academic year in which the study was conducted. Two Grade 12 biology classes were selected through convenience sampling based on their availability during scheduled biology lessons.

The main analytic sample consisted of 64 students, including 23 male and 41 female students aged approximately 17–18 years. Participation was voluntary, and no personally identifying information was collected.

Before the main data collection, the adapted instrument was pilot-tested with an independent sample of 196 students from the same study site. The pilot participants were not included in the main study sample, and no participant contributed data to both stages of the study. The pilot data were used exclusively to examine the internal consistency of the adapted instrument before its administration to the main sample.

Administrative permission was obtained from the relevant local education authority and the participating school. Because the participants were minors, parental consent was obtained before data collection, and students provided assent before participating. All responses were collected anonymously, and the identity of the participating school was omitted from the manuscript and supporting materials.

Instrument

Digital health literacy was measured using an adapted version of the Digital Health Literacy Instrument (DHLI) originally developed by Van Der Vaart and Drossaert (2017). The present study employed the four-dimensional version evaluated by Agormedah et al. (2022), comprising Information Searching, Self-Generated Content, Evaluating Reliability, and Determining Relevance. These dimensions were selected because they represent digital health information skills relevant to students' engagement with virus-related information in biology learning.

The instrument was translated into Indonesian using a conceptual translation approach intended to preserve the meaning and conceptual substance of the original items. The adaptation process emphasized terminological clarity, contextual relevance to virus-related biology learning, and readability for senior high school students. References to coronavirus in the original instrument were broadened to "viruses or related topics" to align the items with the biological content addressed in the study. The complete original English items, their Indonesian adaptations, and their dimensional mapping are presented in Appendix A.

The response format was modified from the original four-point scale to a five-point Likert scale ranging from 1 (very difficult) to 5 (very easy). This modification was intended to provide students with a more differentiated response range. Because the translation, contextual adaptation, and scale modification could affect the instrument's measurement properties, its selection and evaluation were informed by the Consensus-based Standards for the Selection of Health Measurement Instruments framework (Mokkink et al., 2010).

The adapted DHLI consisted of 12 items, with three items representing each of the four dimensions. Table 1 presents the dimensions, number of items, sample statements, and measured aspects.

Table 1. Dimensions of the Digital Health Literacy Instrument

Dimension	Number of items	Sample statement	Measured aspect
Information Searching	3	"When searching for information about viruses on the internet, how easy is it for you to find the information you need?"	Ability to search for and locate digital health information
Self-Generated Content	3	"When writing messages on forums or social media about viruses, how easy is it for you to communicate your questions or concerns?"	Ability to formulate and communicate health-related content digitally
Evaluating Reliability	3	"How easy is it for you to assess whether information about viruses is reliable?"	Ability to assess the reliability and credibility of digital information
Determining Relevance	3	"How easy is it for you to determine whether the information you find is relevant to your needs?"	Ability to determine the relevance and applicability of information

Content Review

Content appropriateness was examined through expert judgment involving two doctoral-level lecturers in Biology Education, each with more than ten years of experience in instrument development and biology learning assessment. The review focused on semantic equivalence, contextual relevance to virus-related biology learning, terminological clarity, and item readability for senior high school students. The experts considered all items suitable for use after minor revisions.

Pilot Testing and Internal Consistency

Before the main survey, the adapted DHLI was pilot-tested with an independent sample of 196 students from the study site. These participants were separate from the 64 students included in the main analysis. The pilot test was conducted to examine the internal consistency of the instrument after its translation, contextual adaptation, and modification from a four-point to a five-point response scale.

In the pilot sample, Cronbach's alpha coefficients ranged from 0.604 to 0.678 across the four dimensions, while McDonald's omega coefficients ranged from 0.628 to 0.679. Corrected item–total correlations ranged from 0.359 to 0.533. These results provided preliminary evidence of relatively consistent internal reliability patterns across the four dimensions within the study setting. The complete pilot-test results are presented in Appendix B.

For transparency, internal consistency was recalculated using the main study dataset (N = 64). The overall 12-item scale yielded a Cronbach's alpha coefficient of $\alpha = 0.659$. Dimension-level reliability was examined using Cronbach's alpha, McDonald's omega, corrected item–total correlations, and mean inter-item correlations, as reported in Table 2.

Table 2. Item Descriptive Statistics, Item–Total Correlations, and Internal Consistency Reliability Indices of the Digital Health Literacy Instrument

Dimension	Item	Mean	SD	Corrected item–total correlation	Mean inter-item correlation	Cronbach's α	McDonald's ω
Information Searching	SI1	3.77	0.87	0.421	0.334	0.600	0.603
	SI2	3.67	0.86	0.389			
	SI3	3.44	0.94	0.418			
Self-Generated Content	SG1	3.25	0.98	0.168	0.267	0.527	0.633
	SG2	3.48	1.11	0.476			
	SG3	3.55	0.94	0.410			
Evaluating Reliability	ER1	3.05	0.97	0.346	0.257	0.506	0.521
	ER2	3.31	0.97	0.247			
	ER3	3.33	0.91	0.379			
Determining Relevance	DR1	3.44	0.87	0.384	0.357	0.626	0.636
	DR2	3.58	0.91	0.444			
	DR3	3.34	0.96	0.480			

Because each dimension consisted of only three items, alpha coefficients were interpreted together with McDonald's omega and mean inter-item correlations. All mean inter-item correlations fell within the recommended range of 0.15–0.50. Nevertheless, the dimension-level coefficients indicated limited to moderate internal consistency, particularly for the Evaluating Reliability dimension. Therefore, small differences among dimensional mean scores should be interpreted cautiously.

The pilot and main-sample analyses showed broadly comparable internal-consistency patterns. However, the pilot testing focused on reliability and did not constitute a complete psychometric revalidation involving factorial validity, measurement invariance, or criterion-related validity. Accordingly, the adapted DHLI was used as a context-specific exploratory instrument for needs assessment and descriptive profiling rather than as a fully revalidated psychometric measure.

Data-Collection Procedure

The study was conducted in two stages. In the first stage, the Indonesian adaptation of the DHLI was pilot-tested with an independent sample of 196 students at the study site. The pilot data were used only to examine the internal consistency of the adapted instrument before the main survey. None of the pilot participants were included in the main analytic sample.

In the second stage, the main data were collected in September 2025 from 64 Grade 12 students. The questionnaire was administered through Google Forms during scheduled biology lessons in a face-to-face classroom setting. The researchers coordinated with the participating biology teachers to arrange questionnaire administration without disrupting regular instructional activities.

Before completing the questionnaire, students received an explanation of the study objectives, participation procedures, voluntary nature of participation, confidentiality safeguards, and use of the collected data. Parental consent had been obtained before data collection, and students provided assent, including electronic confirmation on the first page of the questionnaire.

Students completed the questionnaire independently using their own digital devices. Completion required approximately 20–25 minutes. The researchers and biology teachers supervised the session to clarify procedural questions and support independent completion without directing or influencing students' responses. No names, student identification numbers, or other directly identifying information were collected. The data were stored and managed in accordance with principles of confidentiality and digital data security.

Data Analysis

Data were analyzed using IBM SPSS Statistics version 25. The analysis comprised descriptive profiling, study-specific score categorization, internal-consistency analysis, assumption testing, gender-group comparison, effect-size estimation, and nonparametric sensitivity analysis. Statistical significance was evaluated at $\alpha = 0.05$.

Descriptive Analysis

Descriptive statistics were calculated for the total DHL score and each of the four dimensions. These statistics included the minimum, maximum, mean, standard deviation, frequency, percentage, and 95% confidence interval for the mean. Each DHL dimension contained three items rated from 1 to 5, producing a possible dimensional score range of 3–15. The 12-item total DHL score ranged from 12 to 60.

No standardized cut-off scores have been established for the DHLI. Therefore, the inadequate, problematic, and sufficient categories used in this study were treated as study-specific descriptive categories rather than diagnostic or externally validated classifications. The thresholds were derived using a content-logical approach adapted from DHL categorization procedures reported by Dadaczynski et al. (2022) and Stauch et al. (2025).

The categorization reflected the conceptual meaning of the response options. Scores dominated by responses indicating perceived difficulty were classified as inadequate; scores reflecting mixed perceptions of difficulty and ease were classified as problematic; and scores dominated by responses indicating perceived ease were classified as sufficient. Table 3 presents the operational categories, while Table 4 explains their conceptual derivation.

Table 3. Study-Specific Digital Health Literacy Categories

Category	Score per dimension	Total score	Interpretation
Inadequate	3–7	12–28	Responses are predominantly in the "difficult" to "very difficult" range.
Problematic	8–10	29–43	Responses reflect mixed perceptions of difficulty and ease across items.
Sufficient	11–15	44–60	Responses are predominantly in the "easy" to "very easy" range.

Table 4. Conceptual Rationale for the Study-Specific Digital Health Literacy Category Thresholds

Category	Range	Conceptual basis	Source
Inadequate	12–28	Scores predominantly reflect perceived difficulty in accessing, evaluating, communicating, and using digital health information.	Adapted from content-logical categorization procedures used in DHLI-based studies (Dadaczynski et al., 2022; Stauch et al., 2025)
Problematic	29–43	Scores reflect mixed perceptions of difficulty and ease across DHLI tasks and represent a transitional descriptive level.	Adapted from DHLI categorization logic
Sufficient	44–60	Scores predominantly reflect perceived ease in accessing, evaluating, communicating, and using digital health information.	Adapted from content-logical categorization procedures used in DHLI-based studies (Dadaczynski et al., 2022; Stauch et al., 2025)

Gender-Group Comparison

An independent-samples t-test was conducted to examine whether total DHL scores differed between male and female students. Before conducting the test, normality within each gender group was evaluated using the Shapiro–Wilk test, and homogeneity of variance was assessed using Levene's test.

In addition to statistical significance, the mean difference, its 95% confidence interval, and Cohen's d were reported to describe the magnitude and precision of the observed group difference. Because the total score was derived from summed Likert-scale responses, a Mann–Whitney U test was also conducted as a nonparametric sensitivity analysis. Agreement between the parametric and nonparametric findings was used to assess the robustness of the gender comparison.

RESULTS AND DISCUSSION

Overall Digital Health Literacy Profile

Students' total Digital Health Literacy (DHL) scores ranged from 27 to 58, with a mean of 41.20 (SD = 6.69). The 95% confidence interval for the mean ranged from 39.53 to 42.87, indicating the estimated precision of the sample mean. Based on the study-specific categorization criteria, the mean total score was classified within the problematic category (Table 5).

Table 5. Descriptive Statistics for Students' Digital Health Literacy Scores

Variable	*N*	Min	Max	Mean	SD	95% CI for the mean	Category
DHL total score	64	27	58	41.20	6.69	39.53–42.87	Problematic

Figure 3 presents the distribution of total DHL scores. The histogram shows a relatively symmetrical distribution, with most scores concentrated within the problematic range.

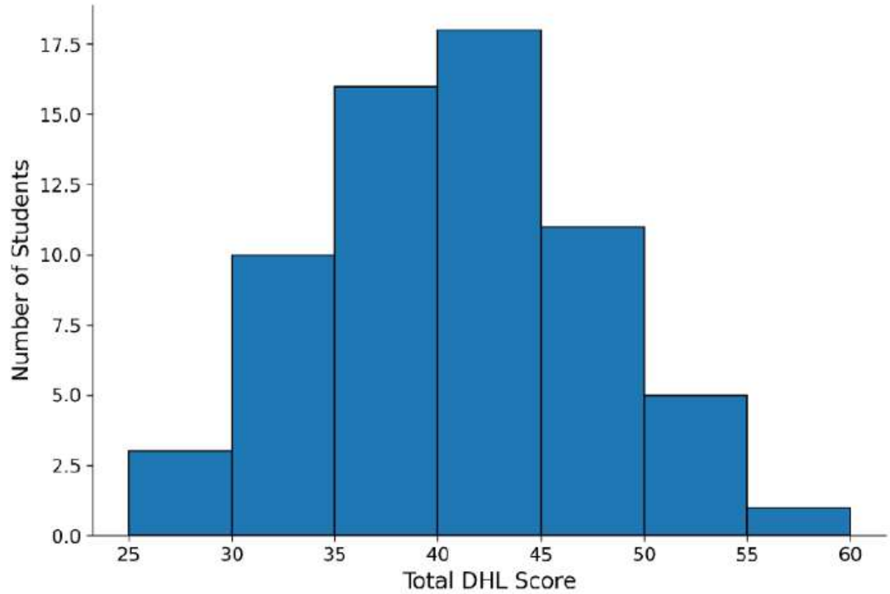

Figure 3. Histogram showing the distribution of total Digital Health Literacy scores among senior high school students

Table 6 presents the frequency and percentage of students in each DHL category. Most students were classified in the problematic category (70.31%), followed by the inadequate category (17.19%). Only 12.50% of students reached the sufficient category. Figure 4 provides a visual summary of this distribution.

Table 6. Distribution of Students across Digital Health Literacy Categories

Category	Number of students	Percentage (%)
Inadequate	11	17.19
Problematic	45	70.31
Sufficient	8	12.50
Total	**64**	**100.00**

These findings show that most students had not reached the sufficient DHL threshold. A dimension-level analysis was therefore conducted to identify students' relative strengths and the specific aspects of DHL that required greater attention.

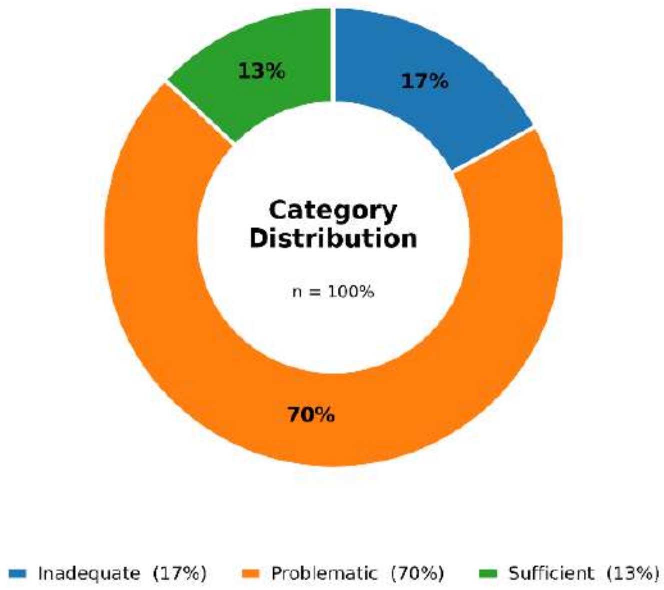

Figure 4. Distribution of students across Digital Health Literacy categories

Digital Health Literacy Profile by Dimension

Dimension-Level Descriptive Statistics

Students' DHL profiles varied across the four dimensions. Table 7 presents the score ranges, means, standard deviations, 95% confidence intervals, and McDonald's omega coefficients for each dimension.

Information Searching had the highest mean score (M = 10.87, SD = 1.99, 95% CI [10.38, 11.37]), followed by Determining Relevance (M = 10.36, SD = 2.07, 95% CI [9.84, 10.88]) and Self-Generated Content (M = 10.28, SD = 2.18, 95% CI [9.74, 10.83]). Evaluating Reliability had the lowest mean score (M = 9.69, SD = 2.02, 95% CI [9.18, 10.19]). Based on the study-specific thresholds, all four dimensions were classified within the problematic category.

Table 7. Digital Health Literacy Scores by Dimension

Dimension	Min	Max	Mean	SD	95% CI	ω	Category
Information Searching	5	15	10.87	1.99	10.38–11.37	0.603	Problematic
Self-Generated Content	5	15	10.28	2.18	9.74–10.83	0.633	Problematic
Evaluating Reliability	6	14	9.69	2.02	9.18–10.19	0.521	Problematic
Determining Relevance	6	15	10.36	2.07	9.84–10.88	0.636	Problematic

Dimension-level McDonald's omega coefficients ranged from 0.521 to 0.636, indicating limited to moderate internal consistency. These coefficients should be considered when interpreting small differences among the dimension-level means. Complete reliability information is presented in Table 2.

Distribution of DHL Categories across Dimensions

Table 8 and Figure 5 show the distribution of students across the inadequate, problematic, and sufficient categories for each DHL dimension. Most students were classified in the problematic category across all four dimensions.

Table 8. Distribution of Digital Health Literacy Categories by Dimension

Dimension	Category	Number of students	Percentage (%)
Information Searching	Inadequate	8	12.50
	Problematic	44	68.75
	Sufficient	12	18.75
Self-Generated Content	Inadequate	16	25.00
	Problematic	39	60.94
	Sufficient	9	14.06
Evaluating Reliability	Inadequate	18	28.13
	Problematic	38	59.38
	Sufficient	8	12.50
Determining Relevance	Inadequate	13	20.31
	Problematic	42	65.63
	Sufficient	9	14.06

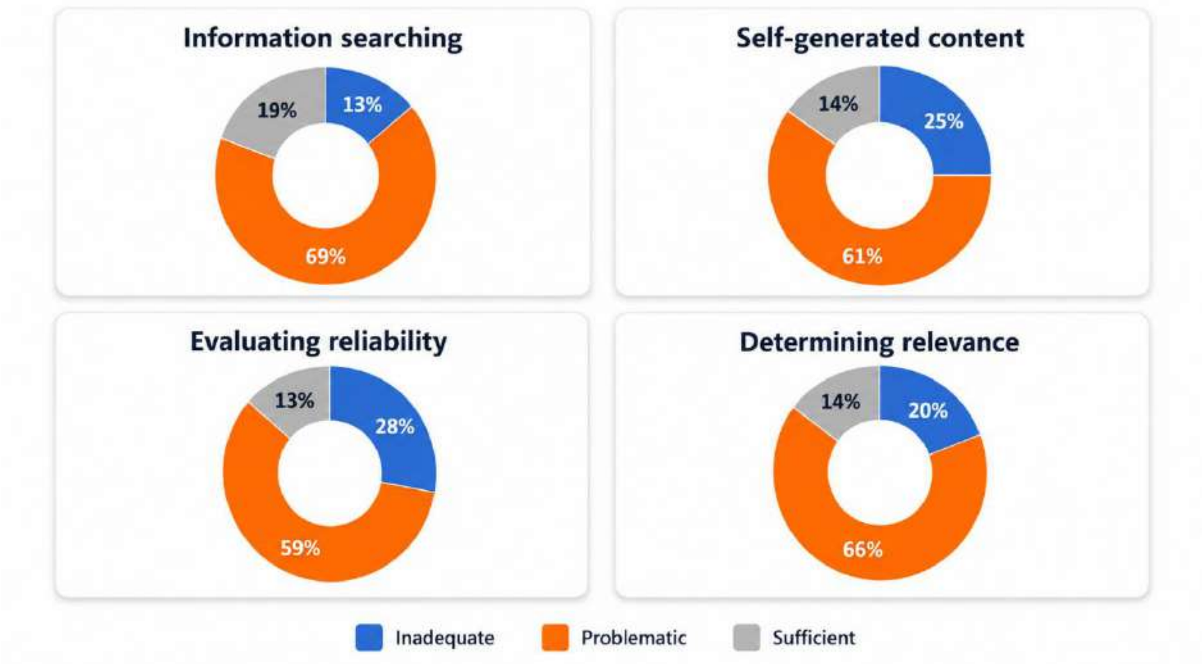

Figure 5. Distribution of Digital Health Literacy categories by dimension

Gender Differences in Digital Health Literacy

Inferential analysis was conducted to examine whether total DHL scores differed between male and female students. The Shapiro–Wilk test indicated that DHL scores did not significantly deviate from normality for either male students ($W = 0.981$, $p = 0.916$) or female students ($W = 0.972$, $p = 0.413$). Levene's test was also nonsignificant ($F = 0.484$, $p = 0.489$), indicating that the homogeneity-of-variance assumption was satisfied (Table 9).

Table 9. Assumption Checks for the Gender Comparison

Test	Statistic	df	*p*
Shapiro–Wilk test: male students	$W = 0.981$	23	0.916
Shapiro–Wilk test: female students	$W = 0.972$	41	0.413
Levene's test	$F = 0.484$	1, 62	0.489

Male students had a mean DHL score of 41.26 (SD = 6.23), while female students had a mean score of 41.17 (SD = 7.01) (Table 10).

Table 10. Descriptive Statistics for Digital Health Literacy Scores by Gender

Gender	*N*	Mean	SD
Male	23	41.26	6.23
Female	41	41.17	7.01

The independent-samples t-test found no statistically significant difference between male and female students, $t(62) = 0.051$, $p = 0.959$. The mean difference was 0.09, with a 95% confidence interval ranging from −3.42 to 3.60. Cohen's d was 0.013, indicating a negligible standardized difference between the two groups (Table 11).

Table 11. Independent-Samples t-Test for Digital Health Literacy Scores by Gender

Test	*t*	df	*p*	Mean difference	95% CI for the mean difference	Cohen's *d*
Independent-samples *t*-test	0.051	62	0.959	0.09	−3.42 to 3.60	0.013

Because the total DHL score was derived from summed Likert-scale responses, a Mann–Whitney U test was conducted as a nonparametric sensitivity analysis. The analysis also found no significant gender difference, $U = 466.50$, $Z = -0.07$, $p = 0.944$ (Table 12). The consistency of the parametric and nonparametric results indicates that the present data provide no evidence of a meaningful gender difference in total DHL scores.

Table 12. Mann–Whitney U Sensitivity Analysis

Test	*U*	*Z*	*p*
Mann–Whitney U test	466.50	−0.07	0.944

Discussion

Overview of the Main Findings

This study identified three principal findings. First, most students were classified as having problematic DHL based on the study-specific descriptive thresholds. Second, Information Searching represented the students' relative strength, whereas Evaluating Reliability was the weakest dimension. Third, no statistically significant difference in total DHL scores was found between male and female students.

The predominance of problematic DHL broadly aligns with international studies showing that adolescents frequently experience difficulties in understanding and critically evaluating digital health information (Stauch et al., 2025; Okan et al., 2023). Evidence from the Health Literacy Survey Europe similarly indicates that adolescents may encounter difficulties when evaluating the reliability of online information (Okan et al., 2023). In Australia, Taba et al. (2022) found that 58% of students had moderate DHL, with identifying credible information sources among the principal challenges.

In Indonesia, these findings illustrate the disparity between widespread internet access and the capacity to use digital information critically. Internet penetration among adolescents has been reported to reach 98.20% (APJII, 2023), while results from PISA and other assessments continue to indicate limitations in students' literacy and information-processing abilities (OECD, 2023). Extensive digital exposure therefore does not necessarily translate into the ability to evaluate evidence, judge source credibility, or use health information appropriately.

The observed DHL profile may also be consistent with learning environments in which students have limited opportunities to evaluate digital information systematically. Biology learning may emphasize conceptual knowledge about viruses, vaccines, and immune responses without always requiring students to examine the validity of related online claims (Subiantoro et al., 2021). Technology use that is dominated by entertainment and passive engagement with social media may further limit students' experience in assessing the credibility of scientific content and increase their vulnerability to health misinformation (Jewarut & Sumarni, 2022; Cuan-Baltazar et al., 2020; Tümer & Sümen, 2022).

Recent reviews indicate that credibility-evaluation skills remain underdeveloped when science learning does not systematically integrate digital health literacy practices (Salim et al., 2024). Conversely, inquiry-based and case-based approaches integrating digital literacy have been associated with improvements in scientific process skills and critical evaluation (Yolanda et al., 2025). Activities involving the analysis of digital sources, health misinformation, website credibility, and scientific evidence may also strengthen digital literacy, health literacy, and evidence-based reasoning (Nguyen et al., 2021; Vrdelja et al., 2021). The present findings therefore support the need for biology learning that provides explicit opportunities to evaluate sources, interpret scientific evidence, and apply biological concepts when examining digital information (Subiantoro et al., 2021; Jewarut & Sumarni, 2022).

Information Searching as a Relative Strength

Information Searching had the highest mean score among the four dimensions, although it remained within the problematic category. This result suggests that students perceived themselves as relatively more capable of locating virus-related digital health information than of evaluating or applying that information. Similar patterns have been reported by Dadaczynski et al. (2021) and Sakellari et al. (2024), who found that young people frequently demonstrate relatively high confidence in online information searching.

However, perceived ease in finding information does not necessarily indicate the ability to assess its quality. McGrew (2020) observed that adolescents often focus on locating information rather than investigating its origin, evidentiary basis, or credibility. As a result, they may accept content that appears persuasive without verifying the expertise of its author or comparing it with other sources.

Within biology learning, students may routinely use search engines to locate information for assignments about viruses, vaccines, or immune responses. Nevertheless, these activities may remain technical or superficial when students retrieve or reproduce information without connecting it to scientific concepts such as viral replication, host–pathogen interactions, and immune mechanisms (Subiantoro et al., 2021; López et al., 2023; Krieg et al., 2019). Thus, students' relative confidence in searching for information should be complemented by structured opportunities to analyze, interpret, and verify the scientific content they locate.

Evaluating Reliability as the Principal Weakness

Evaluating Reliability emerged as the weakest dimension in the students' DHL profiles. This result indicates that students perceived greater difficulty in determining whether virus-related digital health information was credible, accurate, and supported by appropriate evidence. Such difficulty may reflect limitations not only in factual biological knowledge but also in the epistemic skills required to evaluate source quality and the evidentiary basis of digital claims. This pattern is consistent with studies showing that adolescents often experience difficulty verifying online sources and critically examining empirical evidence (Kearney et al., 2020; Santos et al., 2017).

Evaluating reliability requires attention to several source characteristics, including the clarity of authorship, institutional affiliation, publication date, commercial interests, supporting references, and consistency across sources. Previous research suggests that adolescents may instead rely on surface-level indicators, such as visual appeal, popularity, familiarity, or consistency with existing beliefs, rather than scientific authority and evidentiary quality (Wineburg & McGrew, 2017; McGrew, 2020; Dadaczynski et al., 2021). Consequently, persuasive content distributed through social media may be perceived as comparable to information produced by scientific institutions or qualified experts.

This weakness is educationally important when students encounter claims such as *"viruses become more dangerous every time they mutate"* or *"vaccines are ineffective because viruses constantly change."* Although these specific claims were not directly assessed in the questionnaire, they illustrate the types of digital statements that require evaluation of authorship, empirical support, information recency, and consistency with established biological knowledge. Most viral mutations are neutral and do not necessarily increase virulence, while vaccine effectiveness is assessed through clinical evidence and continued epidemiological monitoring (Callaway, 2020; Plante et al., 2020).

Students' difficulty in evaluating reliability may also involve limited engagement in cross-source verification or in comparing digital claims with relevant biological concepts, including viral replication, immune responses, and herd immunity. Previous research indicates that adolescents may process digital information superficially and may not routinely verify information across multiple sources (Santos et al., 2017; Cuan-Baltazar et al., 2020). Social media environments may intensify this difficulty because their distribution mechanisms often prioritize popularity and rapid engagement rather than scientific accuracy (Tümer & Sümen, 2022).

Biology instruction should therefore provide explicit practice in identifying source authority, recognizing commercial interests, assessing information recency, distinguishing empirical claims from unsupported opinions, and evaluating whether digital information is coherent with established scientific principles. Such instruction is particularly important because exposure to health misinformation may influence both students' understanding of biological concepts and their health-related decisions.

Challenges in Determining Information Relevance

Determining Relevance had a mean score of 10.36 (SD = 2.07), with observed scores ranging from 6 to 15. Although students appeared able to locate various forms of digital health information, they reported greater difficulty deciding whether that information was applicable to their needs or relevant to the biological topic under investigation. This pattern is consistent with Tyrrell and Calinger (2022), who noted that students may experience difficulty selecting information that directly supports a particular scientific question or learning task.

In biology learning, determining relevance requires more than identifying information containing familiar keywords. Students must evaluate whether the information addresses the question being investigated and connect it with relevant concepts, such as host–pathogen interactions, immune responses, transmission mechanisms, or epidemiological principles. Without these connections, students may collect large amounts of information while failing to identify which evidence is most appropriate for the learning objective.

Reliance on social media may further complicate relevance judgments because content on these platforms is often brief, decontextualized, and organized around user engagement rather than conceptual coherence (Machado & Rodrigues, 2022). Strengthening students' biological reasoning may therefore help them determine whether digital information is scientifically relevant to a specific claim, problem, or health-related decision.

Limitations in Producing Digital Scientific Content

The Self-Generated Content dimension had a mean score of 10.28 (SD = 2.18), with scores ranging from 5 to 15. This result indicates that students experienced difficulty formulating health-related questions, expressing their ideas clearly, and composing digital messages that other people could understand. These findings are broadly consistent with Navarrete-Muñoz et al. (2024), who demonstrated the educational importance of supporting students in producing and communicating evidence-based scientific content.

Producing digital scientific content requires students to select relevant information, construct an argument, represent knowledge accurately, and communicate scientific concepts clearly. These processes are more cognitively demanding than merely retrieving or consuming information. Darmaji et al. (2022) similarly emphasized that engagement in scientific argumentation and content production may contribute to students' conceptual accuracy and scientific understanding.

The Self-Generated Content items in the present study assessed students' perceived ability to formulate questions, express opinions, and write understandable digital messages. Activities such as producing summaries, annotated infographics, or educational posts may therefore serve as instructional extensions through which students practice organizing and communicating virus-related scientific information. Such activities should include explicit guidance on evidence selection, conceptual accuracy, source attribution, and communication for a defined audience.

Gender Differences in Digital Health Literacy

The analysis found no statistically significant difference in total DHL scores between male and female students, and the estimated effect size was negligible. This finding is consistent with studies reporting a narrowing gender gap in digital literacy and DHL among young people, particularly in educational contexts where digital resources are broadly available (Zhang, 2024; Nguyen et al., 2021; Stauch et al., 2025).

One possible explanation is that male and female students within the participating classes had broadly comparable opportunities to access digital devices and online learning resources. National data indicate that internet use among Indonesian school-aged adolescents is increasingly widespread across gender groups (APJII, 2023). However, access patterns were not measured directly in the present study, and this explanation should therefore be interpreted cautiously.

Digital activities related to biology learning, including searching for scientific information and accessing online resources, may also be provided to all students without gender-based differentiation. Previous research suggests that DHL may be shaped more strongly by learning opportunities and instructional design than by gender alone (Dadaczynski et al., 2021). Nevertheless, the present study did not directly evaluate the instructional practices experienced by the participating students.

The absence of a significant difference in total scores does not establish complete equivalence between male and female students. Gender-related differences may still occur in preferred information sources, search strategies, or patterns of engagement with health information even when overall DHL scores are comparable (Santos et al., 2017; Vrdelja et al., 2021). In addition, the unequal group sizes and relatively small sample limited the ability to detect small differences. The findings therefore support the use of inclusive DHL instruction while avoiding the assumption that all students necessarily engage with digital health information in the same way.

Pedagogical Implications for Virus-Focused Biology Learning

Source-Credibility Evaluation

The problematic overall DHL profile, particularly the weakness in Evaluating Reliability, indicates a need to integrate source-evaluation activities into virus-focused biology learning. Students could examine health-related hoaxes, identify the authors and institutional affiliations of online materials, trace the evidence cited in digital articles, and compare social media claims with peer-reviewed scientific publications. These activities may strengthen students' awareness of how credibility is established in digital environments (McGrew, 2020; Cuan-Baltazar et al., 2020).

A structured credibility-evaluation task could require students to assess several social media posts or online articles concerning vaccines, viral mutations, or disease transmission. A rubric could guide students to examine authorship, institutional authority, publication date, commercial interests, supporting evidence, and consistency across sources. Students could then compare and justify their evaluations in small groups. Source-evaluation activities of this kind may support reflective judgment and evidence-based reasoning (McGrew, 2020; Suwono et al., 2023).

Claim–Evidence–Relevance Mapping

To strengthen the Determining Relevance dimension, students could complete a claim–evidence–relevance mapping activity using digital content related to topics such as immune responses, viral transmission, or disease prevention. Students would identify a central claim, examine the evidence provided, and explain how the information relates to the biological concept and learning objective under investigation.

This approach is consistent with socio-scientific issues, problem-based learning, and digital inquiry models, which encourage students to connect scientific knowledge with authentic health-related problems (Salim et al., 2024; Suwono et al., 2023; Mohebi et al., 2018; Falcon et al., 2024). The task could also require students to reject information that is scientifically accurate but irrelevant to the specific question being examined.

Production of Evidence-Based Digital Content

The difficulties identified in Self-Generated Content indicate that students should also be provided with opportunities to communicate scientific information rather than only consume it. One possible task would require students to create an annotated infographic or digital poster explaining virus replication, infection mechanisms, or immune responses. Students would support their explanations with peer-reviewed publications or information from recognized health and educational institutions.

Producing evidence-based content may help students organize scientific ideas, identify gaps in their understanding, and communicate complex concepts to a defined audience. Such activities may support both conceptual understanding and scientific communication skills (Kunze et al., 2021; Mahanal et al., 2022). Interactive media, including biological simulations, three-dimensional animations, and visualizations of viral processes, may further assist students in connecting abstract biological concepts with the digital information encountered outside the classroom (Teplá et al., 2022; Stadlinger et al., 2021).

These pedagogical implications should be interpreted as proposed applications of the study findings rather than as interventions evaluated in the present research. Their effectiveness should be examined through future classroom-based studies.

Limitations and Directions for Future Research

This study has several limitations. First, the main sample was drawn through convenience sampling from a single public senior high school in Malang, East Java, Indonesia. The identity of the school was withheld to protect institutional and participant confidentiality. Because school context, instructional practices, socioeconomic conditions, and access to digital technology may differ across locations, the findings should be interpreted as a contextual profile rather than as population-level estimates. Second, the main analytic sample was relatively small, and the gender groups were unequal in size. These conditions limited the statistical power to detect small gender differences. The nonsignificant result should therefore be interpreted as an absence of evidence for a gender difference within this sample rather than as proof of complete equivalence between male and female students.

Third, DHL was measured using a self-report instrument. Students' ratings reflected their perceived ease in performing digital health information tasks and did not provide direct evidence of their actual performance. Self-report responses may be influenced by inaccurate self-assessment or social-desirability bias, particularly because the questionnaire was completed in a supervised classroom setting. Future research should combine self-report instruments with performance-based or scenario-based assessments requiring students to evaluate authentic digital information. Fourth, the instrument underwent several adaptations, including translation into Indonesian, contextual modification to virus-related topics, selection of four DHLI dimensions, and modification of the response scale. An independent pilot test involving 196 students from the same study site provided preliminary evidence of internal consistency before the main data collection. However, the pilot analysis did not constitute a comprehensive psychometric revalidation, and several dimension-level coefficients remained limited to moderate. Future studies should examine factorial validity, measurement invariance, criterion-related validity, and reliability using larger and more diverse samples.

Fifth, the inadequate, problematic, and sufficient categories were derived through a content-logical procedure and were used only for descriptive interpretation. They should not be treated as standardized diagnostic thresholds. Future research should investigate whether empirically supported interpretive benchmarks can be developed for secondary-school populations. Finally, the study did not directly assess scientific reasoning, classroom instructional practices, digital-access patterns, or students' actual exposure to misinformation. Interpretations concerning these factors are therefore contextual and theory-informed rather than directly tested. Future research should use mixed-methods and longitudinal designs to examine how learning experiences, digital behavior, biological knowledge, and performance-based DHL develop and interact over time.

CONCLUSIONS

This study provides a contextual profile of digital health literacy (DHL) among senior high school students in virus-focused biology learning. Based on the study-specific descriptive thresholds, most students were classified within the problematic DHL category. Information Searching emerged as their relative strength, whereas Evaluating Reliability was the weakest dimension. These findings indicate that students perceived themselves as relatively capable of locating digital health information but less capable of evaluating its credibility, determining its relevance, and communicating it effectively.

No statistically significant difference in total DHL scores was found between male and female students, and the estimated effect size was negligible. Thus, the present data provide no evidence of a meaningful gender difference within the sampled classes. DHL-oriented instruction may therefore be designed inclusively for all students while remaining responsive to individual differences in digital experience and information-use practices.

The findings support the explicit integration of digital health literacy into virus-related biology instruction. One feasible application is a two-week "DHL in Virology" mini-unit incorporating source evaluation, cross-source verification, claim–evidence–relevance mapping, and the production of evidence-based digital content. These activities may help students strengthen their evaluative judgment, scientific communication, and evidence-based reasoning when engaging with digital health information. Overall, this study offers an empirical basis for developing biology learning practices that respond more directly to the challenges of digital health information.

RECOMMENDATIONS

Future studies should evaluate the effectiveness of DHL-oriented biology learning through multi-school, mixed-methods, and classroom-based intervention designs. Particular attention should be given to performance-based assessments of students' ability to evaluate the credibility and relevance of virus-related digital health information.

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Conflict of Interest Statement

The authors declare that they have no financial, professional, or personal conflicts of interest that could have influenced the conduct, interpretation, or reporting of this study.

Ethical Approval

This study was conducted in accordance with established principles of educational research ethics. Administrative permission was obtained from the relevant local education authority and the participating school before data collection. Because all participants were minors, written parental consent and student assent were obtained prior to participation. Participation was voluntary, and students were informed about the study objectives, procedures, confidentiality safeguards, and their right to decline or withdraw without penalty. No names, student identification numbers, or other directly identifying information were collected. All responses were recorded anonymously, stored securely, and used exclusively for research purposes. The identity of the participating school was withheld to protect institutional and participant confidentiality.

Data Availability

The data that support the findings of this study are available on request from the corresponding author, [SZ]. The data are not publicly available due to privacy or ethical restrictions.

Author Contributions Statement

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Sindi Kharomah	✓	✓			✓	✓	✓	✓	✓		✓		✓	✓
Siti Zubaidah	✓			✓						✓		✓		
Hendra Susanto	✓			✓						✓		✓		
Iwan Hadiqul Fuad		✓				✓			✓					

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

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Appendix

Appendix A. Indonesian Adaptation of the Digital Health Literacy Instrument (DHLI) (Agormedah et al., 2022)

Dimension	Item Code	Original English Item	Indonesian Item
Information Searching Mencari Informasi	SE1	When you search the Internet for information on coronavirus or related topics, how easy or difficult is it for you to make a choice from all the information you find?	Ketika Anda mencari informasi di internet tentang virus atau topik terkait, seberapa mudah atau sulit bagi Anda untuk memilih informasi yang tepat dari berbagai informasi yang ditemukan?
	SE2	When you search the Internet for information on coronavirus or related topics, how easy or difficult is it for you to use appropriate words or search queries to find the information you are looking for?	Ketika Anda mencari informasi di internet tentang virus atau topik terkait, seberapa mudah atau sulit bagi Anda menggunakan kata kunci atau istilah pencarian yang tepat untuk menemukan informasi yang Anda butuhkan?
	SE3	When you search the Internet for information on coronavirus or related topics, how easy or difficult is it for you to find the exact information you are looking for?	Ketika Anda mencari informasi di internet tentang virus atau topik terkait, seberapa mudah atau sulit bagi Anda menemukan informasi yang benar-benar sesuai dengan yang Anda cari?
Self-Generated Content Menghasilkan Konten	EX1	When typing a message (on a forum or social network) about coronavirus or related topics, how easy or difficult is it for you to clearly formulate your question or health-related concern?	Ketika menulis pesan (di forum atau media sosial) tentang virus atau topik terkait, seberapa mudah atau sulit bagi Anda merumuskan pertanyaan atau permasalahan kesehatan secara jelas?
	EX2	When typing a message (on a forum or social network) about coronavirus or related topics, how easy or difficult is it for you to express your opinions, thoughts, or feelings in writing?	Ketika menulis pesan (di forum atau media sosial) tentang virus atau topik terkait, seberapa mudah atau sulit bagi Anda mengungkapkan pendapat, pikiran, atau perasaan secara tertulis?
	EX3	When typing a message (on a forum or social network) about coronavirus or related topics, how easy or difficult is it for you to write your messages so that others understand exactly what you mean?	Ketika menulis pesan (di forum atau media sosial) tentang virus atau topik terkait, seberapa mudah atau sulit bagi Anda menyusun pesan agar orang lain dapat memahami maksud Anda dengan tepat?
Evaluating Reliability Menilai Keandalan	EV1	When you search the Internet for information on coronavirus or related topics, how easy or difficult is it for you to decide whether the information is reliable or not?	Ketika Anda mencari informasi di internet tentang virus atau topik terkait, seberapa mudah atau sulit bagi Anda menilai apakah informasi tersebut dapat dipercaya atau tidak?
	EV2	When you search the Internet for information on coronavirus or related topics, how easy or difficult is it for you to decide	Ketika Anda mencari informasi di internet tentang virus atau topik terkait, seberapa mudah atau sulit bagi Anda menilai apakah informasi

Dimension	Item Code	Original English Item	Indonesian Item
		whether the information is written with commercial interests?	tersebut dibuat dengan kepentingan komersial (misalnya untuk menjual produk)?
	EV3	When you search the Internet for information on coronavirus or related topics, how easy or difficult is it for you to check different websites to see whether they provide the same information?	Ketika Anda mencari informasi di internet tentang virus atau topik terkait, seberapa mudah atau sulit bagi Anda membandingkan beberapa situs untuk melihat apakah informasi yang disajikan konsisten?
Determining Relevance	DR1	When you search the Internet for information on coronavirus or related topics, how easy or difficult is it for you to decide whether the information you found is applicable to you?	Ketika Anda mencari informasi di internet tentang virus atau topik terkait, seberapa mudah atau sulit bagi Anda menentukan apakah informasi tersebut relevan dengan kondisi Anda?
	DR2	When you search the Internet for information on coronavirus or related topics, how easy or difficult is it for you to apply the information you found in your daily life?	Ketika Anda mencari informasi di internet tentang virus atau topik terkait, seberapa mudah atau sulit bagi Anda menerapkan informasi tersebut dalam kehidupan sehari-hari?
	DR3	When you search the Internet for information on coronavirus or related topics, how easy or difficult is it for you to use the information you found to make decisions about your health?	Ketika Anda mencari informasi di internet tentang virus atau topik terkait, seberapa mudah atau sulit bagi Anda menggunakan informasi tersebut untuk mengambil keputusan terkait kesehatan Anda (misalnya tindakan pencegahan, kebersihan, risiko, dan pencegahan penyakit)?

Apendix B. Reliability pilot test result (N=196)

Dimension	Item	Mean	SD	rit	Cronbach's α	McDonald's ω
Information Searching	SI1	3.16	0.998	0.497	0.678	0.679
	SI2	3.05	1.068	0.503		
	SI3	3.06	1.001	0.473		
Self-Generated Content	SG1	3.06	0.964	0.367	0.604	0.648
	SG2	2.87	0.952	0.521		
	SG3	2.86	0.889	0.359		
Evaluating Reliability	ER1	2.90	0.906	0.408	0.653	0.667
	ER2	2.90	0.950	0.533		
	ER3	2.84	0.963	0.455		
Determining Relevance	DR1	2.94	0.978	0.375	0.608	0.628
	DR2	2.99	0.925	0.510		
	DR3	3.18	0.979	0.372		