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Kidney Health Literacy in Biology Learning: Indicator Patterns, Gender Differences, and Learner Clusters in Papua, Indonesia

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ABSTRACT

Kidney health literacy among adolescents remains under-examined within specific biology topics, particularly in eastern Indonesia. This study investigated self-reported kidney health literacy in biology learning among 108 eleventh-grade students (43 males, 65 females) from two senior high school in Sentani, Jayapura Regency, Papua, Indonesia. The instrument was adapted from the attitude questionnaire component of the kidney health literacy instrument developed by Wahyuni and Subiantoro (2024), covering four indicators: accessing, understanding, appraising, and applying kidney health information. Results showed that students were predominantly distributed across the Problematic (46.3%) and Sufficient (45.4%) categories. A one-sample t-test indicates that the population mean index did not differ significantly from the upper boundary of the Problematic category (M = 33.20, SD = 4.98; p = .680). Appraising was the weakest and most variable indicator (M = 30.86, SD = 7.58), while applying was the strongest (M = 34.95). No significant gender differences emerged from the Chi-Square, Fisher's Exact,, and Independent Samples T-Tests, although female students showed greater score variability (SD = 5.74 vs. 3.61). K-Means cluster analysis identified three learner profiles: Proficient (23.1%), Underdeveloped (40.7%), and Transitional (36.1%). Appraising produced the highest F-value (F = 169.131), indicating that this indicator contributed most strongly to between-cluster differentiation. These findings suggest that appraising represents the most critical gap in students' kidney health literacy and should be an explicit instructional target in biology learning on the human excretory system.

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INTRODUCTION

Biology learning at the senior high school level has an important role not only in developing students' conceptual understanding of living systems but also in cultivating health literacy as a meaningful learning outcome. Health literacy refers to a person's knowledge, motivation, and competence to access, understand, evaluate, and apply health information in order to make appropriate health-related decisions (WHO, 2021). In biology education, this competence is closely related to students' ability to connect scientific concepts with everyday health issues. Ploomipuu et al. (2019) showed that health literacy overlaps with scientific literacy, but also includes ethical, psychological, and socio-cultural dimensions.

Recent studies have also highlighted the relevance of health literacy in biology learning. Husamah et al. (2024) reported that health literacy has emerged as one of the literacy types promoted in biology education, while Pradipta and Situmorang (2024) suggested that model-based learning approaches, particularly problem-based learning, can support the development of health literacy among high school students. These findings imply that health literacy should not be treated merely as an incidental outcome of biology teaching, but as a learning goal that can be deliberately integrated into instructional practice.

Within this framework, kidney health literacy among adolescents deserves particular attention. Nakamura et al. (2025) found that awareness of chronic kidney disease among adolescents remains low. Langham et al. (2022) similarly emphasized the importance of kidney health education and literacy, including the role of schools as early sites for preventive kidney health education. From a science education perspective, these findings point to a persistent gap between what students learn about the kidney in biology class and how far that learning develops into meaningful kidney health literacy competencies.

The socio-cultural setting of Jayapura Regency, Papua, Indonesia, provides an important contextual basis for examining kidney health literacy among high school students. Papuan communities have historically been closely connected to subsistence-based food systems, including sago, tubers, fish, forest products, and locally available foods, while recent socio-economic and dietary changes have increasingly exposed young people to market-based food practices and modern consumption patterns, including ultra-processed foods (UPFs) (Kadir et al., 2020; Nurhasan et al., 2022). Within this context, health-related behaviors among adolescents need to be understood not only as individual choices but also as practices shaped by culture, peer interaction, family habits, food availability, and broader social change.

Dietary transition is particularly relevant to kidney health literacy because kidney health is closely connected to daily food and beverage choices. Increased consumption of high-sodium foods, sugar-sweetened beverages, and ultra-processed foods may contribute to kidney-related risk through several pathways, including elevated blood pressure, metabolic burden, obesity, diabetes risk, and long-term decline in kidney function (Dai et al., 2024; He et al., 2024). These dietary risks are important in biology learning because they allow students to connect the structure and function of the kidneys with real-life decisions about hydration, salt intake, processed foods, and beverage consumption.

Other socio-cultural practices also need to be considered. Some studies have reported alcohol consumption among adolescents in Papua (Violita et al., 2025; Zukaidah et al., 2023), while betel nut chewing remains a long-standing socio-cultural practice in Papuan society and has also been found among adolescents in Jayapura Regency (Lutfianasari & Yusuf, 2025; Watopa, 2019; Mumu & Aninam, 2018). These practices are relevant to biology learning, particularly in topics related to the excretory system and kidney health. Betel nut chewing has been associated with kidney-related disorders (Chang et al., 2022; Wang et al., 2018), while alcohol consumption beginning in adolescence may increase the risk of hypertension or high blood pressure (Chen et al., 2024; Sun et al., 2022), which is itself an important risk factor for kidney disease (Hezam et al., 2024). Therefore, biology learning should not only introduce students to the anatomical and physiological functions of the kidneys, but also develop their ability to evaluate how dietary habits, cultural practices, and health-related behaviors in their daily environment may influence kidney health.

Although health literacy in science education has received increasing attention, empirical studies that measure health literacy within specific biology topics remain limited in Indonesia.

Candrakusuma and Nurhayati (2020) and Ditiaharman et al. (2022) documented health literacy among high school students using general instruments, but these instruments were not explicitly linked to particular curricular topics, making their findings difficult to translate into targeted biology instruction. A similar pattern was found by Damopolii et al. (2025), who measured health literacy among Indonesian high school students in a biology learning context and reported that students generally reached only the basic level, with disease prevention as the weakest domain. However, the findings remained cross-topic and did not clearly identify where intervention was most urgently needed within the biology curriculum. Taken together, these studies suggest that topic-specific measurement is needed to identify students' indicator-level strengths, weaknesses, and literacy profiles. Responding to this need, Wahyuni and Subiantoro (2024) developed an instrument that integrates four health literacy indicators, namely accessing, understanding, appraising, and applying, with kidney biology content. However, its empirical application in real classroom contexts, particularly in eastern Indonesia, remains limited.

Therefore, this study investigates kidney health literacy in biology learning among eleventh-grade students in Sentani, Jayapura Regency, Papua, Indonesia. Specifically, it aims to measure students' kidney health literacy levels, examine indicator patterns, test gender differences, and identify learner clusters based on literacy profiles. Cluster-based profiling is included because aggregate reporting can obscure meaningful sub-group differences in literacy competencies — students at similar overall levels may show contrasting indicator-level strengths and weaknesses that carry distinct instructional implications. This study contributes to biology education research by providing an empirically grounded, indicator-level profile of kidney health literacy within the human excretory system topic. It also demonstrates how topic-specific assessment, supported by inferential statistics, inter-indicator correlation analysis, and cluster-based profiling, can reveal pedagogically meaningful differences in students' health literacy competencies that may not be captured by general instruments or aggregate reporting alone.

METHOD

This study employed a descriptive cross-sectional survey design to describe the category of kidney health literacy among senior high school students at a single point in time. This design enables systematic documentation of literacy profiles across a defined population without manipulating variables, making it appropriate for generating baseline data to inform instructional improvement in biology education.

Participants consisted of 108 eleventh-grade students from two senior high schools in Jayapura Regency, Papua, Indonesia. Both schools were selected based on two considerations: (1) both schools include the human excretory system as part of the eleventh-grade (phase F) in Merdeka curriculum; and (2) the inclusion of one public and one private school introduces institutional variation that strengthens sample representativeness in the local educational context.

Purposive sampling was conducted based on three criteria: (1) students were enrolled in eleventh grade and had completed the human excretory system instructional unit prior to data collection, ensuring all participants had received the relevant biological content; (2) students were present during the scheduled data collection period; and (3) students completed the questionnaire in full. Data collection was therefore conducted after the excretory system unit had been taught so that the instrument measured students' literacy in a context where biology content knowledge had been introduced rather than as a pre-instructional baseline. The final sample comprised 43 male students and 65 female students.

The instrument used in this study was adapted from the attitude questionnaire component of the human kidney health literacy instrument developed by Wahyuni and Subiantoro (2024). The original instrument consisted of three components: attitude, knowledge, and skills. However, the present study used only the attitude questionnaire because the research focused on students' self-reported kidney health literacy orientation in biology learning, rather than on direct testing of conceptual knowledge or performance-based skills. The attitude questionnaire was originally adapted from the HLS-EU-Q47 and contextualized to daily lifestyle practices related to kidney health. It covered four indicators of health literacy: accessing health information, understanding health information, appraising health information, and applying health information. The adapted version used in this study consisted of 16 retained statement items distributed across the four indicators. Prior to the main data collection, the instrument was piloted with 30 eleventh-grade students in Jayapura Regency to examine the validity of the instrument. This step was necessary because instrument validation is essential to ensure that the items accurately measure the intended construct and produce reliable data in science learning evaluation (Suryadi et al., 2025). The pilot test produced a Cronbach's alpha of 0.855, indicating good internal consistency, with corrected item-total correlations ranging from 0.322 to 0.730. Therefore, all 16 items were retained for the main study. The pilot analysis yielded a Cronbach's alpha of 0.855, exceeding the value from the original study ($\alpha = 0.786$), with corrected item-total correlations ranging from 0.322 to 0.730 (all > 0.30). No item deletion was found to substantially increase overall alpha, confirming that all 16 items were retained.

Data collection was conducted after the researcher obtained written permission from school principals and coordinated with each school's biology teacher. Students completed the questionnaire independently during regular class sessions at a pre-determined time. The researcher monitored the process and verified response completeness immediately after each session. No student responses were excluded due to incomplete data.

Data analysis was conducted in two phases. In the first phase, item scores were processed and converted into a health literacy index value ranging from 0 to 50 using a formula as shown in equation (1) adapted from Duong et al. (2017):

$$Indeks = (mean - 1) * \frac{50}{3} \tag{1}$$

where mean represents the average item score per student, 1 is the scale minimum, 3 is the four-point Likert scale range, and 50 is the maximum index value. The resulting index values were classified into four literacy categories following HLS-EU Consortium criteria (as cited in Duong et al., 2017): Inadequate (0–25), Problematic (26–33), Sufficient (34–42), and Excellent (43–50). Indicator-level index scores were calculated separately by averaging items belonging to each indicator.

In the second phase, a series of inferential and multivariate analyses was conducted. First, a one-sample t-test was performed to determine whether the sample mean index differed significantly from the upper boundary of the problematic category (test value = 33). Second, gender differences were examined through cross-tabulation with Chi-Square across four literacy categories, followed by Fisher's Exact Test on a dichotomized variable (Below Sufficient vs. Sufficient and Above) to ensure assumption compliance and an independent samples t-test comparing mean literacy index scores between groups. Third, Spearman rank-order correlations were performed to examine relationships among the four indicator index scores, given that Shapiro-Wilk normality testing confirmed significant deviation from normality across all indicators ($p < .001$). Fourth, K-Means Cluster Analysis with three clusters was conducted to identify distinct learner profiles based on patterns across the four indicator indices. All analyses were performed using IBM SPSS Statistics version 25.

RESULTS AND DISCUSSION

Results

Kidney Health Literacy is Predominantly at the Problematic Level

Analysis of 108 students revealed that the sample was predominantly in the Problematic (n = 50, 46.3%) and Sufficient (n = 49, 45.4%) literacy categories, while only six students reached the Excellent level (5.6%) and three were categorized as Inadequate (2.8%) as illustrates in Figure 1. The near-equal split between these two middle categories indicates that students occupy a transitional literacy zone where basic engagement with kidney health information has developed, but the evaluative and critical competencies required for higher literacy have not yet consolidated.

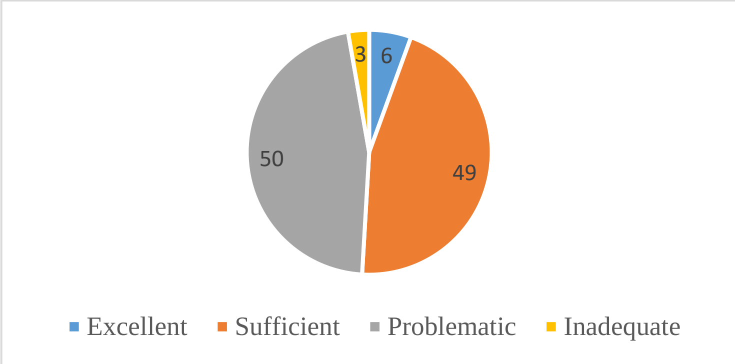

Fig.1. Distribution of students' categories for kidney health literacy

To determine whether the sample mean had exceed the Problematic threshold at the population level, a one-sample t-test was conducted with a test value of 33, representing the upper boundary of problematic category. The result confirmed that the sample mean index (M = 33.20, SD = 4.98) did not differ significantly from the test value; t (107) = 0.414, p = 0.680, 95% CI [−0.752, 1.148]. This result indicates that the population mean index is statistically indistinguishable from the problematic threshold, confirming that kidney health literacy in this context has not consistently reached the sufficient level.

Appraising is the Weakest and Most Variable Indicator

To identify which specific competency dimensions drove this overall pattern, indicator-level scores were examined in the following section.

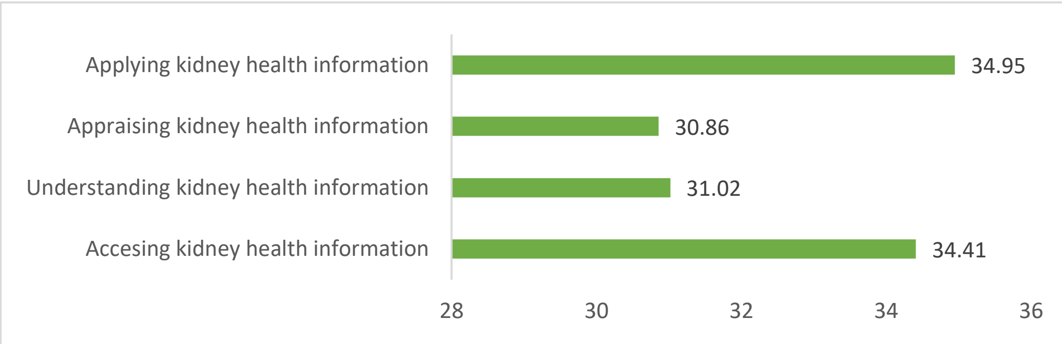

Fig.2. Mean index score for each kidney health literacy indicator

As shown in Figure 2, a consistent differential performance pattern is evident across all four indicators. Student scored highest on applying kidney health information (M = 34.95, SD = 5.86), followed by accessing (M = 34.41, SD = 6.68), understanding (M = 31.02, SD = 5.79), and appraising kidney health information (M = 30.86, SD = 7.58). Only the applying and accessing indicators reached the lower boundary of the sufficient category (≥ 34), while understanding and evaluating remained within the problematic range. The appraising indicator warrants particular attention for two reasons. First, it produced the lowest mean index score alongside the widest standard deviation (SD = 7.58), indicating the greatest individual variation in appraisal capacity. Second, its left-skewed distribution (mean = 30.86 < median = 33.33) suggests a subgroup of students with substantially lower appraising scores pulling the mean down.

No Significant Gender Differences, but Greater Variability Among Female Students

Given this indicator-level profile, the analysis next examined whether the pattern was consistent across male and female students. Figure 3 presents the distribution of literacy categories by gender.

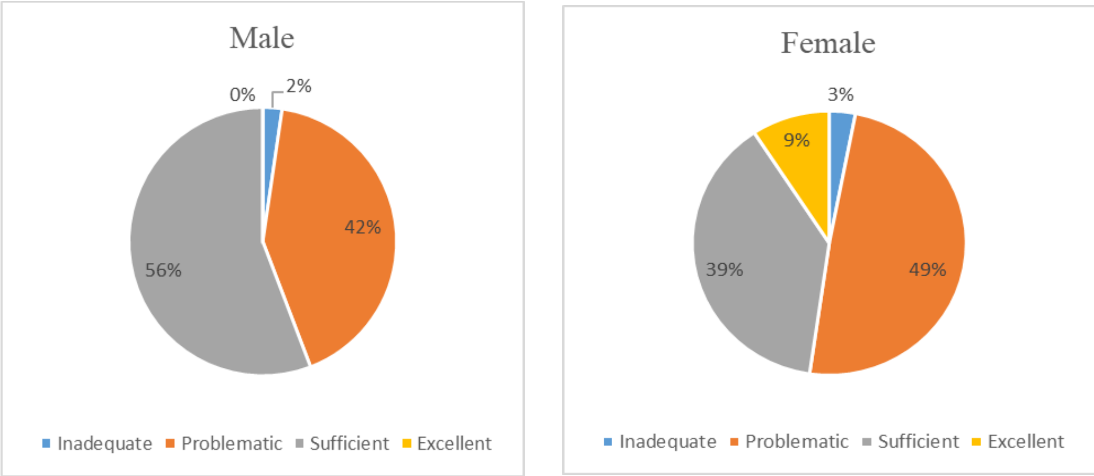

Fig.3. Distribution of kidney health literacy categories by gender

As shown in Figure 3. male students were predominantly concentrated in the Sufficient 56% and Problematic 42% categories, with none reaching the Excellent level. Female students showed a wider distributional spread, with all six Excellent-category students being 9% female. However, the Sufficient category in the Duong et al. (2017) framework indicates that literacy is already adequate for most situations; it is, therefore, the Problematic and Inadequate categories that require significant instructional support. In this sample, 44% of male students and 52% of female students fell below the Sufficient threshold, indicating that the majority of students in both groups had not yet achieved adequate kidney health literacy. Table 1 presents the summary of inferential tests conducted to examine gender differences.

Table 1. Summary of Inferential Tests for Gender Differences in Kidney Health Literacy

Analysis	Statistic	Value	df	p-value	Decision
Chi-Square (4 categories)	χ^2	6.043	3	.110	Not significant*
Fisher's Exact Test (2×2 dichotomy)	—	—	—	.437	Not significant
Levene's Test	F	9.920	—	.002	Unequal variances
Independent Samples T-Test	t	−0.243	105.790	.809	Not significant

**Chi-Square result must be interpreted with caution: 50% of cells have expected values < 5. Fisher's Exact Test is the primary inferential result for gender comparison.*

As shown in Table 1, Pearson's chi-square showed no statistically significant distributional difference across four literacy categories ($p = .110$), although this result requires caution because 50% of cells had expected counts below five. Fisher's Exact Test on the dichotomized variable (Below Sufficient vs. Sufficient and Above), which fully met expected count assumptions (minimum expected count = 21.10), confirmed no significant association between gender and literacy category ($p = .437$). The independent samples t-test further confirmed no significant difference in mean literacy index scores between male ($M = 33.07$, $SD = 3.61$) and female students ($M = 33.29$, $SD = 5.74$); $t\,(105.79) = -0.243$, $p = .809$. Notably, Levene's test indicated significantly unequal variances between groups ($F = 9.920$, $p = .002$), reflecting substantially greater score variability among female students.

Appraising is Structurally Distinct: Evidence from Correlations and Learner Profiles

Table 2 presents the Spearman rank-order correlation matrix among the four kidneys health literay indicators.

Table 2. Spearman Rank-Order Correlation Matrix Among Four Kidney Health Literacy Indicators

Indicator	Accessing	Understanding	Appraising	Applying
Accessing	1.000	.466**	.411**	.442**
Understanding	.466**	1.000	.409**	.418**
Appraising	.411**	.409**	1.000	.361**
Applying	.442**	.418**	.361**	1.000

*** Correlation is significant at the 0.01 level (2-tailed). N = 108.*

As shown in Table 2, all six indicator pairs showed statistically significant positive correlation at p < .01, values ranging from rs=.361 to rs=.466, confirming that the indicators are positively related but represent partially distinct competencies. The strongest correlation was between accessing and understanding (rs =.466), reflecting the cognitive proximity of these two foundational competencies. The weakest correlation — though still significant — was between appraising and applying (rs =.361), indicating these two indicators are more structurally independent from one another than any other indicator pair in the instrument.

To determine whether this structural independence of evaluating translated into identifiable learner groups, K-Means Cluster Analysis with three clusters was conducted. Prior to analysis, Shapiro-Wilk testing confirmed that all four indicator indices deviated significantly from normality (p < .001. Table 3 presents the final cluster centers and learner profiles.

Table 3. Final Cluster Centers and Kidney Health Literacy Learner Profiles (K-Means, k = 3)

Indicator	Cluster 1: Proficient (n=25, 23.1%)	Cluster 2: Underdeveloped (n=44, 40.7%)	Cluster 3: Transitional (n=39, 36.1%)
Accessing	42 (Sufficient)	31 (Problematic)	33 (Problematic)
Understanding	37 (Sufficient)	28 (Problematic)	30 (Problematic)
Appraising	39 (Sufficient)	23 (Inadequate)	34 (Sufficient)
Applying	40 (Sufficient)	33 (Problematic)	34 (Sufficient)

Note: Score categories follow HLS-EU Consortium criteria (Duong et al., 2017): Inadequate (0–25), Problematic (26–33), Sufficient (34–42), Excellent (43–50). Distances between final cluster centers: Cluster 1–2 = 22.477; Cluster 1–3 = 14.008; Cluster 2–3 = 11.065.

As shown in Table 3, `ANOVA confirmed that all indicators significantly differentiated clusters (p <.001). Critically, the appraising indicator produced the highest F-value (F = 169.131) among all indicators, statistically confirming that appraising capacity is the primary dimension distinguishing learner profiles. Three distinct profiles emerged from the analysis. Cluster 1 (Proficient Health Literacy Learners, n=25,23.1%) achieved consistently sufficient scores across all four indicators. Cluster 2 (Underdeveloped Health Literacy Learners, n=44,40.7%), the largest group, showed the weakest performance across all indicators, with the appraising index falling in the Inadequate category (index=23) and all other scores in the problematic range. Cluster 3 (Transitional Health Literacy Learners, n=39, 36,1%) displayed a mixed profile in which appraising and applying reached the lower boundary of the Sufficient category (index=34 each), while accessing and understanding remained in the Problematic range (33 and 30, respectively). The largest inter-cluster distance was between Cluster 1 and Cluster 2 (22.477), confirming these as the most contrasting learner profiles in the sample.

Discussion

The inferential finding that the sample mean index (M=33.20) was statistically indistinguishable from the upper boundary of the Problematic category (p =.680) carries educational significance that descriptive frequency reporting alone cannot fully convey. Rather than simply characterizing nearly half of students as Problematic, this result indicates that the population as a whole has not yet consistently achieved sufficient kidney health literacy. This pattern is theoretically aligned with Nutbeam's (2000) three-level model of health literacy, which distinguishes functional, interactive, and critical health literacy. Within this framework, functional health literacy refers to basic skills for accessing and understanding factual health information, while interactive and critical health literacy require more advanced cognitive and social skills. Critical health literacy, in particular, involves the ability to critically analyze health information and use it to gain greater control over health-related decisions and conditions. The distribution of students across literacy categories in this study reflects this uneven development. Most students appear to occupy a transitional zone between Problematic and Sufficient literacy, suggesting that basic kidney health knowledge may have begun to develop, but higher-order competencies needed for critical kidney health literacy have not yet been firmly established.

The differential performance across the four indicators provides a theoretically meaningful explanation of this asymmetry because each indicator reflects different cognitive demands and different forms of measurement. The applying indicator produced the highest mean index score (M = 34.95), but this finding requires careful interpretation. In Wahyuni and Subiantoro's (2024) instrument, the applying items are based on self-report measures of perceived capability and behavioral intention rather than direct observation of actual health-related action. Therefore, high scores on this indicator should be interpreted as students' self-assessed readiness to use kidney health information, not as direct evidence of demonstrated behavioral competence. This distinction is important because students may report a strong willingness to act even when their appraising competence remains limited. Willingness to use health information does not necessarily require the epistemic capacity to judge whether that information is credible, scientifically grounded, or free from commercial bias.

The appraising indicator, by contrast, requires more advanced cognitive processing. It requires students to assess evidence quality, compare claims across sources, and distinguish scientifically supported recommendations from commercially motivated narratives. This interpretation is consistent with Sørensen et al. (2012) integrated model of health literacy, in which appraising health information involves interpreting, filtering, judging, and evaluating information before it can be used for health-related decision making. The left-skewed distribution of appraising scores (mean = 30.86 < median = 33.33) further suggests that this deficit is particularly acute among a specific subgroup of students rather than being evenly distributed across the population. This indicator pattern suggests that while biology instruction may have begun to develop students' foundational readiness to access and use kidney health information, the deliberate engagement with authentic health problems require for appraising competence has not yet been systematically provided.

The inter-indicator correlation structure provides further empirical support for this interpretation. All six indicator pairs showed statistically significant positive correlations (rs=.361–.466, p<.01), indicating that the four indicators are related components of kidney health literacy. However, the moderate size of these correlations also suggests that the indicators are not interchangeable and represent partially distinct competencies within the same construct. The strongest correlation, observed between accessing and understanding (rs = .466), is consistent with the integrated health literacy framework proposed by Sørensen et al. (2012), in which accessing and understanding represent closely connected early competencies in health information processing. Accessing refers to the ability to seek, find, and obtain health information, whereas understanding refers to the ability to comprehend the information that has been accessed. Their cognitive proximity may explain their stronger co-occurrence in this sample.

The weakest correlation, observed between appraising and applying (rs=.361), suggests a greater separation between students' capacity to critically appraise kidney health information and their self-reported readiness to use it. Appraising is more cognitively demanding than applying, which centers on using information for health-related decisions. This pattern supports the argument that willingness to act on health information does not necessarily indicate the capacity to judge whether that information is scientifically valid. The finding is also consistent with Nutbeam's (2000) framework, which holds that critical health literacy requires more advanced, cognitive and social skills that go substantially beyond those associated with functional or interactive literacy.

This structural pattern is relevant to school-based health literacy research. Paakkari and Paakkari (2012) conceptualize health literacy as a learning outcome that includes theoretical knowledge, practical knowledge, critical thinking, self-awareness, and citizenship. Their model suggests that some components of health literacy can be developed through content exposure, whereas critical thinking and citizenship require learning conditions that engage students with authentic health problems. Jenkins et al. (2023) similarly reported that schools are important settings for developing critical health literacy, but the action-oriented dimension of critical health literacy is rarely supported in school contexts. Sykes and Wills (2018) also showed that interventions may improve some appraisal-related competencies, while broader dimensions such as understanding health determinants and participation in social or political action remain difficult to develop. Therefore, the correlation pattern in this study supports the construct validity of the Wahyuni and Subiantoro (2024) instrument by showing that the four indicators are empirically related yet partially independent, as expected in the HLS-EU-based framework of accessing, understanding, appraising, and applying health information.

The supplementary cluster analysis reinforces and extends these indicator-level findings by identifying three empirically distinct learner profiles. The Proficient cluster (23.1%) achieved sufficient scores across all four indicators, whereas the Underdeveloped cluster (40.7%), the largest group, showed the most severe deficit in appraising, with an index score in the Inadequate category (23.00). This pattern confirms that appraising competence represents the most critical kidney health literacy gap in this population. The ANOVA result further supports this interpretation. Among the four indicators, appraising produced the highest F-value (F=169.131), indicating that this indicator contributed the strongest between-cluster differentiation.

The Transitional cluster (36.1%) presents a theoretically notable pattern. Students in this group achieved sufficient appraising and applying scores despite weaker accessing and understanding. This profile challenges the assumption that health literacy always develops in a strictly linear sequence from foundational to higher-order competencies. Instead, it suggests that different components of kidney health literacy may develop unevenly across learners. This interpretation is consistent with Sørensen et al.'s (2012) integrated model, which conceptualizes accessing, understanding, appraising, and applying as related but distinct competencies shaped by personal, situational, and social determinants. The relatively stronger appraising and applying scores in the Transitional cluster may also reflect adolescents' exposure to informal health information channels, such as social media or peer discussion. However, this explanation should be treated as tentative because the present study did not directly measure students' media exposure or peer-based health information practices. Freeman et al. (2023) support this cautious interpretation by showing that adolescents' trust in health information on social media depends on the perceived credibility of platforms, users, and content.

Collectively, these three profiles suggest that biology instruction should not assume a uniform developmental trajectory across learners. Students may enter the classroom with different configurations of kidney health literacy. Therefore, biology learning should combine foundational support for accessing and understanding kidney health information with explicit activities that strengthen in-depth appraisal reasoning and evidence-based decision making.

The absence of statistically significant gender differences across the Chi-Square test, Fisher's Exact Test, and the Independent Samples T-Test suggests that kidney health literacy in this sample did not vary systematically by gender. Both male and female students were predominantly distributed across the Problematic and Sufficient categories, indicating that insufficient appraising health literacy was a shared condition across gender groups. This pattern shifts the interpretation away from gender as the main explanatory factor and toward broader learning conditions experienced by students. This is relevant because the development of critical health literacy depends strongly on instructional design, student activities, learning context, and opportunities to practice critical thinking about health information.

Nevertheless, the substantially greater score variability among female students (SD = 5.74 vs. 3.61 for males; Levene's $F = 9.920$, $p = .002$) warrants further attention. This result indicates that female students were more heterogeneous in their kidney health literacy scores, even though their mean score did not differ significantly from that of male students. The descriptive pattern, in which all six Excellent-category students were female while females also comprised a large proportion of the Problematic category, suggests greater within-group variation among female students. This variation may reflect differences in individual engagement with health information, informal health-seeking practices, or prior exposure to kidney health issues. However, this explanation should be treated as tentative because the present study did not directly measure students' health information-seeking behavior, media exposure, or peer-based information practices.

These findings support gender-neutral instructional design as the primary response to the identified literacy gap, while also highlighting the need for differentiated learning support across both gender. Biology instruction should therefore focus on strengthening appraising health literacy for all students through evidence appraisal, comparison of health claims, and critical discussion of kidney health information, rather than assuming that one gender group requires a fundamentally different instructional approach.

The literacy profile identified in this study is directionally consistent with findings from adolescent health literacy research in other national and international contexts. Jatu et al. (2024) found that most high school students in Ethiopia had limited health literacy, whereas Karagözoğlu and İlhan (2024) reported that adolescent health literacy in Turkey was generally at a moderate level. Direct numerical comparison is not appropriate because these studies used different instruments, scoring procedures, and categorical frameworks. However, the tendency for adolescents to cluster at intermediate or limited literacy levels appears consistent across contexts. This pattern suggests that the transitional literacy profile observed in the present study reflects a broader challenge in developing advanced and critical dimensions of health literacy among adolescents.

Studies in Indonesia provide a relevant contextual comparison, although their findings need to be interpreted according to the instruments used. Candrakusuma and Nurhayati (2020), for example, reported relatively high general health literacy among high school and vocational school students in Surabaya using the HLS-EU-Q16, but their functional health literacy results based on the NVS showed that most students remained in limited or possibly limited categories. Ditiaharman et al. (2022) also showed that more than half of high school students had sufficient health literacy, while emphasizing the relevance of internet-based health information seeking among adolescents. More recently, Damopolii et al. (2025) examined high school students’ health literacy across the domains of health promotion, disease prevention, and healthcare in a biology learning context, showing that students had not yet reached a proficient level of health literacy. The present study extends this national pattern by using topic-specific measurement on kidney health literacy. It demonstrates that the literacy weakness is not only located at the general domain level, but also appears at the indicator level, with appraising competence emerging as the most consistently underdeveloped dimension across learner profiles.

Three interrelated implications emerge for biology education from the convergence of these findings. First, the population mean index remained statistically indistinguishable from the Problematic threshold even after students had completed the excretory system instructional unit. This result suggests that appraising health literacy should not be treated as an incidental outcome of content-based biology teaching. Instead, it needs to be positioned as an explicit instructional target within the topic of the human excretory system. This interpretation is consistent with recent reviews showing that health literacy in science and biology learning can be strengthened through intentional instructional designs, including problem-based learning, practical and theoretical tasks, appropriate media use, curriculum support, and innovative science learning models. The indicator-level evidence in this study provides a more specific basis for this recommendation by identifying appraising competence as the dimension that requires deliberate instructional attention in kidney health literacy learning.

Second, the relatively distinct position of appraising in the correlation and cluster analyses suggests that improving students’ access to and understanding of kidney health information does not automatically lead to stronger appraising capacity. Biology instruction should therefore create explicit opportunities for students to assess the credibility, accuracy, and scientific basis of health information in authentic contexts. Jacque et al. (2015) showed that high school biology curricula can integrate claims evaluation, data interpretation, and risk assessment to develop health literacy-related skills. Suwono et al. (2021) also provided empirical support for the relevance of problem-based biology learning in promoting students’ health literacy, particularly because biology topics are closely connected to disease and health. In the context of kidney health literacy, these findings imply that students should not only learn the structure and function of the excretory system, but also practice appraising real health claims about hydration, kidney disease prevention, dietary habits, supplements, and other kidney-related health information.

Third, the cluster analysis indicates that differentiated instructional responses are needed. Students whose profiles resemble the Underdeveloped cluster require foundational support across all literacy dimensions, including accessing, understanding, appraising, and applying kidney health information. Students whose profiles resemble the Transitional cluster require a different emphasis: they need reinforcement in accessing and understanding, while their existing appraising and applying orientation should be further developed through evidence-based tasks. This implication is consistent with school-based health literacy intervention research showing that interventions designed from identified learner needs and implemented through contextual, multicomponent classroom activities can improve adolescent health literacy and health-promoting intentions. Therefore, biology instruction should avoid treating the class as a homogeneous group. It should combine common instruction for all students with targeted learning activities that respond to distinct literacy profiles within the classroom.

CONCLUSION AND SUGGESTION

Kidney health literacy among eleventh-grade students in Sentani, Jayapura Regency, was predominantly distributed at the Problematic and Sufficient levels. Inferential testing showed that the population mean was not significantly different from the upper boundary of the Problematic category ($p = .680$). Across the analyses, appraising was the weakest and most variable indicator, while applying was the strongest. Cluster analysis identified three distinct learner profiles, namely Proficient (23.1%), Underdeveloped (40.7%), and Transitional (36.1%), with appraising emerging as the main dimension differentiating the profiles. Gender was not a statistically significant differentiating factor, although female students showed greater score variability. These findings suggest that the appraising dimension represents the most critical gap in students' self-reported kidney health literacy. Biology instruction on the human excretory system should therefore explicitly address students' ability to appraise kidney health information, rather than assuming that this ability will develop automatically through content-based instruction.

Future research should employ intervention designs, including problem-based learning integrated with health literacy goals or inquiry-oriented approaches, to test whether targeted pedagogical strategies can specifically improve the appraising indicator. Qualitative follow-up studies using think-aloud protocols or interviews would deepen understanding of the cognitive and contextual sources of students' difficulty in appraising kidney health information. Comparative studies across schools, regions, and curriculum contexts would clarify whether the learner profiles identified in this study reflect local patterns specific to eastern Indonesia or broader national trends in adolescent kidney health literacy.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS STATEMENT

Conceptualization and methodology, M.N.K. and Y.H.; data collection and formal analysis, N.R.L.R.; writing-original draft preparation, N.R.L.R.; writing-review and editing, Y.H. and N.R.L.R.; supervision, Y.H. and M.N.K. All authors have reviewed and agreed to the published version of the manuscript.

DECLARATION OF GENERATIVE AI SOURCES

In the preparation of this manuscript, the authors used AI-assisted tools to support language refinement, grammar checking, and structural editing. All AI-generated results were reviewed, revised, and verified by the authors against the original research data. The authors take full responsibility for the accuracy, integrity, and final content of this manuscript.

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