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Unveiling the knowing-doing gap in river ecosystem SSI: profiling students' scientific literacy and action competency

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Abstract

Scientific literacy is fundamental for Education for Sustainable Development (ESD), yet a disconnect often exists between students' cognitive understanding and their ability to take responsible environmental action, especially in the context of river ecosystems. This study analyzes the profile of Scientific Literacy and Action Competency among junior high school students within a local Socio-Scientific Issues (SSI) framework. Employing a quantitative descriptive-correlational design, data were collected from 64 students using valid and reliable instruments, including essay tests, portfolios, questionnaires, and observations. The findings reveal that students' average proficiency on both variables remains low, despite a strong positive correlation between them. Crucially, a diagnostic analysis uncovered a significant "knowing-doing gap," in which students' high self-perceptions on Likert scales contrasted with their lower performance on objective tasks, suggesting a potential "illusion of competence". Furthermore, a consistent challenge was identified in written argumentation skills across both variables. The study concludes that while local SSI approaches are gender-inclusive, they require robust instructional scaffolding to bridge the gap between intention and execution. Based on these diagnostic interpretations, we hypothesize that developing adaptive pedagogical interventions, such as Interactive E-Modules based on local SSI, could enhance students' capacity to translate scientific knowledge into concrete, sustainable actions. Future research should focus on the empirical design and validation of such learning materials, as well as on exploring non-cognitive variables such as emotional intelligence.

Abstrak. *Literasi ilmiah merupakan fondasi utama dalam Pendidikan untuk Pembangunan Berkelanjutan (ESD). Namun, seringkali muncul kesenjangan antara pemahaman kognitif siswa dan kemampuan mereka mengambil tindakan lingkungan yang bertanggung jawab, khususnya dalam konteks ekosistem sungai. Penelitian ini bertujuan memprofilkan Literasi Ilmiah dan Kompetensi Aksi siswa SMP terkait Isu Sosio-Saintifik (SSI) lingkungan lokal. Menggunakan desain deskriptif-korelasional kuantitatif, data dikumpulkan dari 64 siswa menggunakan instrumen yang divalidasi, meliputi tes esai, portofolio, kuesioner, dan observasi. Hasilnya menunjukkan bahwa rata-rata penguasaan kedua variabel berada pada kategori rendah, meskipun terdapat korelasi positif yang kuat di antara keduanya. Secara krusial, analisis diagnostik mengungkapkan adanya kesenjangan mengetahui-melakukan (knowing-doing gap) yang signifikan, di mana persepsi diri siswa yang tinggi pada skala Likert kontras dengan kinerja objektif yang lebih rendah, mengindikasikan potensi "ilusi kompetensi". Selain itu, teridentifikasi pula kendala yang konsisten pada keterampilan argumentasi tertulis di kedua variabel. Disimpulkan bahwa pendekatan SSI lokal, meskipun inklusif gender, memerlukan scaffolding instruksional yang kuat untuk menjembatani kesenjangan antara niat dan aksi. Berdasarkan interpretasi diagnostik tersebut, kami menghipotesiskan bahwa pengembangan intervensi pedagogis adaptif, seperti E-Modul Interaktif berbasis SSI lokal, berpotensi meningkatkan kapasitas siswa dalam menerjemahkan pengetahuan ilmiah menjadi tindakan berkelanjutan. Penelitian selanjutnya harus berfokus pada desain empiris dan validasi materi pembelajaran tersebut serta eksplorasi variabel non-kognitif.*

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A. Introduction

Scientific literacy remains a critical educational challenge globally, particularly in Indonesia, as evidenced by students' persistent underperformance in international assessments such as the Programme for International Student Assessment (PISA) over the last decade (Hewi & Shaleh, 2020; Khery et al., 2022; Ramli et al., 2022). This stagnation in scientific proficiency indicates a systemic failure to equip students with the ability to identify scientific issues and explain phenomena scientifically rather than merely recall factual knowledge (Salsabila et al., 2025). In the Indonesian context, this deficiency is particularly acute in the areas of environmental and life science content, highlighting a profound disconnect in understanding local biodiversity and ecosystem dynamics. The urgency to address this deficit extends beyond improving academic metrics because scientific literacy is a fundamental prerequisite for citizens to engage with complex modern challenges and make informed decisions (Hayat, 2024). Contemporary educational discourses emphasize that the relevance of scientific literacy lies in its capacity to foster a sustainability mindset, enabling students to understand the reciprocal impact of human activities on the natural world and their local ecosystems (Dieni et al., 2022; Fajeriadi et al., 2024; Maulana & Abidin, 2023). Therefore, the revitalization of scientific literacy is not only an academic imperative but also a necessary step toward cultivating the cognitive foundation for sustainable living within the framework of Education for Sustainable Development (ESD).

The transition from possessing scientific knowledge to demonstrating sustainable behavior requires the development of action competency, which serves as the operational dimension of ESD. Action competency transcends simple behavior modification or compliant activism by requiring a critical capacity in which students consciously decide to act based on democratic processes and sound scientific reasoning (Oinonen et al., 2023; Olsson et al., 2020; Torsdottir et al., 2024). Conceptually, the dimensions of scientific literacy, such as explaining phenomena scientifically and interpreting data, serve as the necessary cognitive foundation that informs the dimensions of action competency. Specifically, a solid grasp of ecological evidence is expected to directly influence students' volition to act, their capacity to plan, and their execution of practical solutions. However, a significant disconnect often exists: students possess high environmental knowledge yet fail to translate it into tangible action due to a lack of confidence or conflicting values (Chen & Liu, 2020; Olsson et al., 2020; Sass et al., 2020). Consequently, integrating action competency into learning about ecological systems is essential to transform passive learners into active agents of change capable of addressing the multidimensional problems inherent in sustainable development.

A highly promising pedagogical framework for facilitating the simultaneous development of scientific literacy and action competency is the use of Socio-Scientific Issues (SSI). While alternative approaches, such as traditional inquiry or project-based learning, also contribute to scientific literacy and action competency development, SSI distinctly places students at the centre of controversial dilemmas that have both conceptual ties to science and significant social implications, forcing them to negotiate between evidence and ethics (Chen & Liu, 2020; Jensen & Schnack, 1997). Recent empirical studies highlight that the use of local socio-scientific issues explicitly enhances student engagement by connecting abstract scientific concepts with the immediate reality of their communities (Permanasari et al., 2021; Saija et al., 2022; Wisdayana et al., 2025). When students investigate local problems such as regional waste management or local water quality, they experience a heightened sense of ownership and relevance that global issues often fail to provoke (Sari & Wiyarsi, 2021; Sulistina et al., 2024; Yenni et al., 2017). This contextualization within the local ecosystem acts as a catalyst that binds cognitive understanding with the emotional driver necessary for developing robust action competency.

Despite the extensive body of research regarding scientific literacy and the growing interest in action competency, a critical analysis of the literature reveals a distinct gap in the integrated examination of these variables within the context of local socio-scientific issues. A systematic comparison of existing literature shows that previous studies have predominantly examined scientific literacy in isolation, focusing heavily on cognitive mastery or utilizing macro-global contexts (e.g., global climate change) that often lack immediate personal relevance to early adolescent learners (Erman & Sari, 2019; Husniyyah et al., 2023; Roberts & Bybee, 2014). Even when scientific literacy is framed within the context of citizenship, it frequently lacks the empirical measurement of actual behavioral execution (Valladares, 2021). Conversely, research originating from the environmental education domain often investigates action competency by emphasizing psychological drivers, norms, or attitudinal metrics (Kollmuss & Agyeman, 2002; Mogensen & Schnack, 2010), yet frequently fails to anchor these behaviors to rigorous scientific evidence or specific local ecological concepts (Nasor et al., 2023; Sass et al., 2020).

Consequently, while seminal educational frameworks acknowledge the theoretical necessity of combining knowledge and action (Sadler et al., 2016; Wals, 2015), there is a notable scarcity of empirical research that systematically integrates both variables

within a localized SSI framework, particularly concerning river ecosystems. None of these prior studies have adequately addressed how local ecological contextualization serves as the missing operational link between possessing scientific literacy and demonstrating action competency. This research gap constitutes a significant oversight in Biology Education, as the formative years of junior high school represent a crucial developmental period for bridging the 'knowing-doing gap' and establishing lifelong habits toward science and society.

This research aims to examine the current levels of scientific literacy and action competency among junior high school students when engaged with local socio-scientific issues. The study seeks to determine the correlation between students' cognitive understanding of science and their capacity to act, as well as to identify any descriptive diagnostic discrepancies between their perceived competence and actual performance. By focusing on this specific intersection of variables, the study advances existing knowledge by providing empirical baseline data on how local context influences the translation of scientific knowledge into action. The findings from this study offer practical guidance for educators in designing science instruction that effectively bridges the gap between knowing science and acting responsibly for a sustainable future.

B. Material and method

This study employed a quantitative, descriptive-correlational design specifically tailored to the context of environmental biology, to provide a comprehensive analysis of the variables under investigation. We used the descriptive component to capture students' actual proficiency levels in Scientific Literacy and Action Competency within the context of local socio-scientific issues related to river ecosystems. Concurrently, we utilized the correlational design to examine the strength and direction of the relationship between scientific literacy and action competency, as well as to identify any diagnostic discrepancies between student self-perception and their objective performance. It is important to emphasize that this correlational design is intended strictly to establish statistical associations and predictive trends; it does not support causal interpretations between the variables. We selected this dual-design framework to ensure that the research not only mapped the status of student competence but also explained the underlying dynamics between the cognitive and behavioral variables in addressing ecological problems.

The participants in this research comprised 64 junior high school students, 25 males and 39 females, distributed across two distinct classes: Class 8A (N=32) and Class 8F (N=32). This study used a purposive sampling technique to select these groups based on specific criteria: the schools' geographical proximity to a major river ecosystem facing documented pollution issues, their active implementation of the national science curriculum, and the students' foundational exposure to basic ecological concepts during their seventh-grade instruction. While these specific classes were chosen to represent early adolescent learners directly interacting with local SSI, we acknowledge that this non-probability sampling limits the external validity and generalizability of the findings to broader populations. In strict adherence to ethical standards for research involving human subjects, we obtained institutional review board approval prior to data collection. Furthermore, informed consent forms were distributed to and signed by both students and their legal guardians, ensuring that participation was voluntary, that we preserved anonymity, and that we used the data exclusively for academic purposes.

Data collection relied on a set of instruments specifically designed to measure the two primary variables. The Scientific Literacy instrument consisted of 12 items focusing on evaluating cognitive dimensions such as explaining scientific phenomena and interpreting scientific evidence. Examples of these instruments include essay questions requiring students to analyze water quality parameters, portfolio tasks involving the synthesis of pollution impacts on local biodiversity, and observation sheets focusing on scientific argumentation during group work. The Action Competency instrument comprised 18 items measuring operational dimensions like the willingness to act and practical problem-solving. This included essay tests on designing local waste management solutions, a Likert-scale questionnaire to measure self-perceived competence, and observation sheets to assess actual engagement in pro-environmental discussions. We tested the validity and reliability of these instruments rigorously prior to use. Construct validity testing using Pearson correlation confirmed that all items were valid at the 0.01 significance level. Reliability testing demonstrated exceptional internal consistency, yielding Cronbach's Alpha coefficients of 0.973 for both the Scientific Literacy and Action Competency instruments. While these values are exceptionally high, coefficients approaching 1.00 may indicate item redundancy or overlapping constructs. During instrument development, item overlap was examined; however, highly correlated items were intentionally retained to capture the nuanced, multidimensional variations of the local river SSI. We acknowledge this high internal consistency as a psychometric characteristic indicating that the items measure a highly unified, albeit slightly overlapping, construct.

The data analysis procedure commenced with prerequisite tests to ensure compliance with parametric statistical assumptions. We used the Shapiro-Wilk test to assess normality and Levene's test to assess homogeneity of variances between the two classes. Upon satisfying these assumptions, the

analysis proceeded to descriptive statistics to determine the mean, standard deviation, and mastery percentage for each variable. Inferential statistics, specifically the Independent-Samples T-Test, were conducted to evaluate significant differences across demographic factors such as class and gender. Finally, we calculated the Pearson product-moment correlation to quantify the relationship between scientific literacy and action competency. While more advanced analytical approaches, such as Structural Equation Modeling (SEM) or multiple regression, could provide stronger theoretical insights into variable relationships, Pearson correlation and simple regression (coefficient of determination) were selected as the most appropriate methods. This choice is justified by the relatively small sample size (N=64) and the study's methodological scope, which aims to establish baseline empirical associations rather than test complex causal models. We performed all statistical computations using IBM SPSS Statistics version 27 to ensure accuracy and precision.

C. Results and discussion

This study employed a quantitative approach utilizing a descriptive-correlational design. We used a descriptive design to analyze the profiles and students' proficiency levels in Scientific Literacy (SL) and Action Competency (AC). Concurrently, we employed a correlational design to examine the strength of the relationship between the SL and AC variables and to analyze discrepancies among instrument components. Quantitative data were collected from 64 students, comprising 25 males and 39 females. The sample was distributed across two classes, 8A (N=32) and 8F (N=32), which were selected purposively to represent heterogeneous cognitive abilities in the context of river ecosystem issues. Prior to hypothesis testing, the data underwent prerequisite testing for validity, reliability, normality, and homogeneity.

Validity testing using the Pearson correlation indicated that all 12 items of the Scientific Literacy instrument (comprising essay tests, portfolios, and observations) and all 18 items of the Action Competency instrument (comprising essay tests, Likert questionnaires, and observations) were valid, showing significant correlation at the 0.01 level (2-tailed). Reliability testing demonstrated high internal consistency for both variables, yielding a Cronbach's Alpha coefficient of 0.973 for Scientific Literacy and 0.973 for Action Competency. It should be noted that these exceptionally high values may indicate item redundancy or highly overlapping constructs within the instruments. However, these highly correlated items were retained to fully capture the multifaceted and interconnected nature of the local SSI context. Parametric prerequisite tests confirmed that the data satisfied the necessary assumptions. The Shapiro-Wilk normality test indicated normality for both Scientific Literacy (Sig. = 0.205) and Action Competency (Sig. = 0.118). Furthermore, Levene's test for homogeneity revealed that the variances between classes (8A and 8F) were homogeneous for both variables (AC Sig. = 0.082; SL Sig. = 0.112).

The primary findings of this study indicate that the students' average mastery levels for both variables remain in the low category. The classification of student mastery into categories such as 'Low' or 'Moderate' was based on standard criterion-referenced evaluation benchmarks within the Indonesian grading context, where overall scores below 55% are generally defined as low proficiency. As summarized in Table 1, the overall mean score for Action Competency (AC) (N=64) was 44.88 (SD=7.11) out of a maximum score of 90, equivalent to 49.86% mastery. The mean score for Scientific Literacy (SL) was 27.14 (SD=5.87) out of a maximum score of 60, representing 45.23% mastery. The distribution of student categories in Figure 1 confirms the findings in Table 1, where the majority of students for both variables are concentrated in the 'Low' category.

Table 1 Statistics for students' scientific literacy (SL) and action competency (AC) mastery

Statistics	Scientific literacy (SL)	Action competency (AC)
N	64	64
Max. score	60	90
Mean	27.14	44.88
SD	5.87	7.11
Min.	12	29
Max.	44	65
% Mastery	45.23%	49.86%
Category	Low	Low

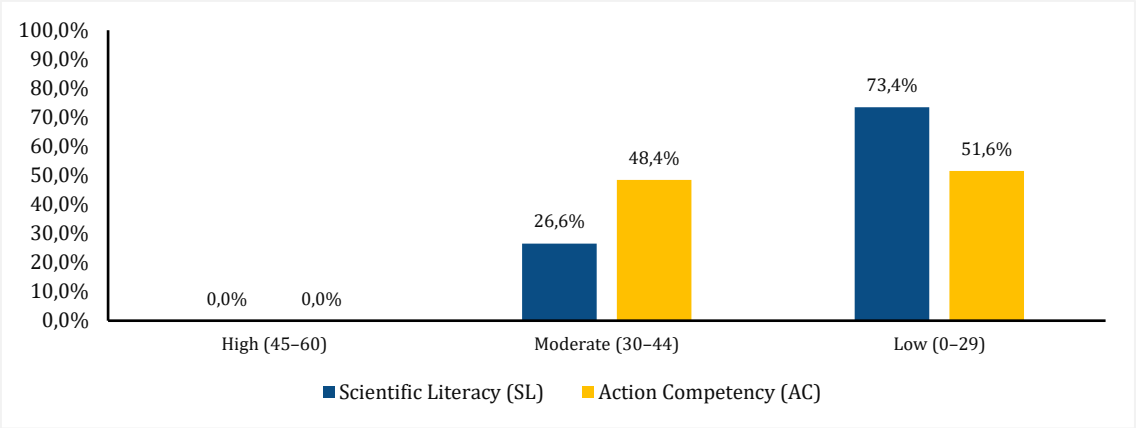

Figure 1 Mastery categories distribution of scientific literacy and action competency

The comparative t-test analysis presented in Table 2 shows a statistically significant difference based on the classes. There is a significant difference in Scientific Literacy, where class 8A (M=30.78, SD=4.79) scored higher than class 8F (M=23.50, SD=3.46); t (62) = 6.45, p < 0.001. We also found a similar difference in Action Competency, where class 8A (M=49.38, SD=5.37) was significantly higher than class 8F (M=40.38, SD=6.01); t (62) = 5.92, p < 0.001. These results underscore that foundational knowledge in ecological principles, likely established by prior instruction, significantly influences students' ability to analyze and propose solutions for complex river issues.

Table 2 Results of independent sample t-test analysis based on class and gender

Variable	Group	N	Mean	SD	t	df	Sig. (2-tailed)	Decision
Scientific literacy (SL)	Class 8A	32	30.78	4.79	6.45	62	< 0.001	Significant difference
	Class 8F	32	23.50	3.46				
Action competency (AC)	Class 8A	32	49.38	5.37	5.92	62	< 0.001	Significant difference
	Class 8F	32	40.38	6.01				
Scientific literacy (SL)	Male	25	27.04	6.26	-0.12	62	0.904	No difference
	Female	39	27.20	5.67				
Action competency (AC)	Male	25	44.40	7.40	-0.45	62	0.654	No difference
	Female	39	45.10	6.99				

Another secondary finding analyzed was a gender comparison. The results of the t-test in Table 2 show that there are no statistically significant differences between male (N=25) and female (N=39) students in terms of Scientific Literacy (t (62) = -0.12, p = 0.904) and Action Competency (t (62) = -0.45, p = 0.654). These findings indicate that in this sample, the level of mastery of SL and AC related to local SSI issues involving the river ecosystem was not influenced by gender. This finding suggests that the SSI pedagogical approach, which focuses on community problem-solving, is gender-inclusive regarding the acquisition of ecological knowledge and the willingness to act.

In addition to comparative analysis, a correlational analysis was also conducted to test the relationship between Scientific Literacy (SL) and Action Competency (AC). The results of the Pearson correlation test, as shown in Figure 2, indicate a strong, statistically significant positive relationship between the two variables (r(62) = 0.89, p < 0.001). The coefficient of determination (R^2) shows that approximately 79.2% of the variability in Action Competency can be explained by its association with students' level of Scientific Literacy concerning ecological issues. The visualization of the correlation between the two variables in Figure 2.

Figure 2 presents a visualization of the Pearson correlation findings between Scientific Literacy (X-axis, Max. 60) and Action competency (Y-axis, Max. 90) for 64 students. Visually, the scatter plot shows a clear pattern where the data points move from the lower left to the upper right and cluster closely around the regression trend line, indicating a strong positive relationship. These results confirm the conclusion that there is a strong positive relationship between the two variables: students with higher Scientific Literacy scores also almost always have higher Action Competency scores.

Further diagnostic analysis of the Action Competency variable in Table 3 shows a gap between students' perceived abilities and their measured performance. The average score for the Likert Questionnaire (perceived willingness and ability) was in the 'Moderate' category (58.7%). However, the average scores for Observation (discussion

performance) (37.3%) and Essay Test (cognitive action) (50.5%) indicate a much lower level of mastery. These findings indicate that students feel (Likert) more competent to address the river ecosystem issue than they can prove (Observation and Test).

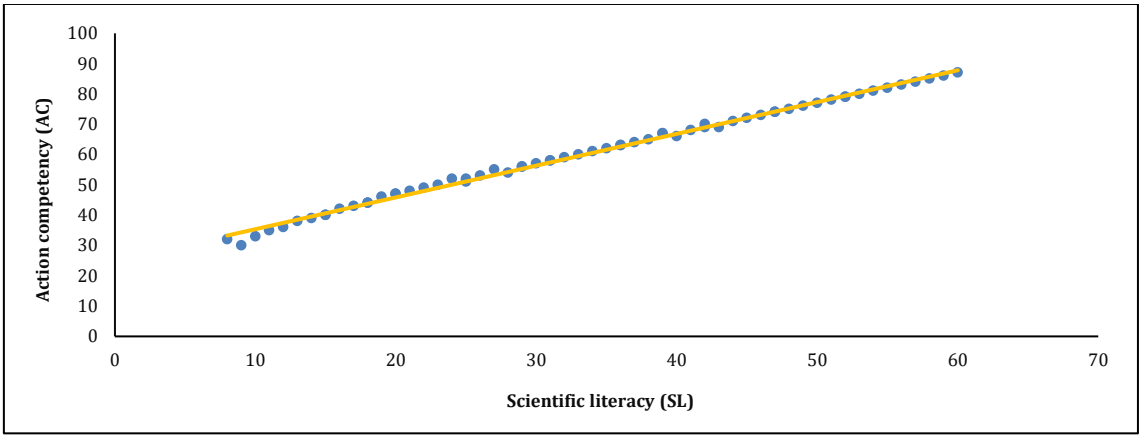

Figure 2 Visualization of the correlation (scatter plot) between scientific literacy (SL) and action competency (AC)

Table 3 Diagnostic analysis of average student mastery gaps (N=64) per instrument

Variable	Instrument	Max. score	Mean	% Mastery
Action competency (AC)	Essay test (ACQ1-Q4)	20	10.11	50.5% (Moderate)
	Likert questionnaire (ACK1-K8)	40	23.47	58.7% (Moderate)
	Observation (ACO1-ACO6)	30	11.29	37.3% (Low)
Scientific literacy (SL)	Essay test (SLQ1-SLQ6)	30	12.48	41.6% (Low)
	Portfolio (SLP1-P2)	10	5.11	51.0% (Moderate)
	Observation (SLO1-SLO4)	20	9.59	47.9% (Low)

The diagnostic analysis of Scientific Literacy in Table 3 shows that students' main weakness lies in cognitive tests. The average score on the Essay Test (SLQ) shows the lowest mastery (41.6%). Slightly better scores were found in Observation (47.5%) and Portfolio (51.0%). That results show that students are weaker at explaining scientific phenomena in writing (Test) than when discussing (Observation) or analyzing data (Portfolio). This suggests a critical deficit in translating complex ecological concepts and logical reasoning into formal written argumentation, which is a key indicator of higher-order scientific literacy needed for addressing environmental issues.

The preceding section presented the quantitative findings, detailing the low mastery levels observed in both Scientific Literacy and Action Competency, the strong positive correlation between the two variables, the lack of gender difference, and the significant diagnostic discrepancy between student self-perception and measured performance. These findings collectively provide the empirical foundation necessary to discuss the core pedagogical and ecological challenges faced by junior high school students when tackling complex local environmental issues. The subsequent discussion interprets these statistical outcomes in light of established educational and ecological literature, focusing specifically on the implications for Biology Education and the effective cultivation of ecologically responsible citizens.

The robust positive correlation identified between Scientific Literacy and Action Competency highlights a strong association between cognitive understanding and environmental action. While this cross-sectional correlational design limits our ability to claim a definitive causal or prerequisite relationship, the findings are consistent with the theoretical postulate that students who genuinely engage in responsible action often possess a solid grasp of the underlying scientific evidence (Dieni et al., 2022; Fajeriadi et al., 2024; Maulana & Abidin, 2023). The strong linear relationship suggests that as students demonstrate a more profound ability to explain ecological phenomena, their recorded capacity to formulate and execute action strategies increases proportionally. This relationship indicates that action competency in the context of socio-scientific issues is closely linked to a cognitively driven process rather than merely an impulsive behavioral response (Febriya & Desnita, 2024; Hayat, 2024; Suryawati et al., 2020; Utami et al., 2025). Consequently, the low proficiency levels observed in both variables can be attributed to the complexity of the local SSI framework especially when integrating multi-faceted concepts of freshwater ecology and community dynamics. The literature characterizes SSI as open-ended and unstructured problems that demand sophisticated, evidence-based reasoning and reflective judgment rather than simple recall (Saad et

al., 2017; Zeidler et al., 2008). This inherent complexity presents a significant hurdle for early adolescents, as it necessitates a rigorous transition from rote memorization to Higher-Order Thinking Skills (HOTS) to effectively negotiate these multifaceted issues (Sadler, 2011; Widad et al., 2025; Zeidler et al., 2008).

A critical analysis of the diagnostic data reveals a notable discrepancy between students' self-reported self-perception and their actual objective performance, highlighting a potential "knowing-doing gap" within the learning process. The phenomenon in which students scored higher on the Likert questionnaire than on the observation and essay tests may suggest what literature refers to as an illusion of competence or social desirability bias. It is important to clarify that this "illusion of competence" is a possible theoretical interpretation of the score discrepancies rather than a directly measured psychological construct in this study. Students seemingly perceive themselves as willing and capable agents of change in solving river pollution issues; however, when confronted with the actual demand to construct arguments or participate in problem-solving discussions, their performance declines (Foerst et al., 2017; Lindsey & Nagel, 2015). This anomaly implies that while the students report an intention to act, they may lack the specific skills to translate that intention into concrete, scientifically justifiable actions. Studies frequently observe this tendency, noting that students' self-perceptions can substantially diverge from their actual problem-solving capabilities in environmental and ecological domains (El Messaoudi et al., 2025; Feldbacher et al., 2021; Roebianto, 2020). This gap underscores that action competency cannot be assumed to develop naturally from positive attitudes alone but requires explicit instructional scaffolding to translate volition into execution related to ecological stewardship (Oinonen et al., 2023; Olsson et al., 2020; Torsdottir et al., 2024).

Interestingly, a closer inspection of the Scientific Literacy components reveals a contrast with the Action Competency. While students struggled with the written Essay Test (41.6%), they demonstrated relatively higher proficiency in Portfolios (51.0%) and Observation (47.9%). This contrast suggests that students possess a latent 'practical literacy' in applied ecology. They can engage with science during hands-on activities but face linguistic barriers when articulating their understanding in formal written assessments (Rahayu et al., 2020; Rahman et al., 2018). The literature suggests that the struggle to translate practical engagement into written argumentation stems primarily from insufficient instructional scaffolding and a lack of dedicated practice in reasoning techniques, rather than from inherent student limitations. This academic literacy gap is exacerbated by limited conceptual mastery of biological principles and low self-confidence, indicating that students require rigorous training to bridge the divide between doing science and articulating it scientifically (Arianti et al., 2024; Herawati, 2015; Suraya et al., 2019).

Furthermore, while the coefficient of determination (R^2) indicates that 79.2% of the variance in Action Competency can be statistically explained by its association with Scientific Literacy, the remaining unexplained variance (20.8%) points to the likely influence of other factors. In the context of environmental behavior theory, this shared variance highlights a strong cognitive link, but the unexplained portion likely represents unmeasured non-cognitive variables such as emotional factors, social pressure, or personal values that also drive student actions, independent of their scientific knowledge regarding ecosystem stewardship. Studies found that environmental behavior is significantly governed by non-cognitive factors, including biospheric values, social norms, and emotional motivations, which account for substantial behavioral variance and often serve as stronger drivers of action than rational knowledge alone (Kollmuss & Agyeman, 2002; Pratama et al., 2024; Steg et al., 2016; Ünal et al., 2017). The evidence suggests knowledge of ecological principles is closely associated with, but may not be solely responsible for, environmental action, with non-cognitive factors providing critical motivational infrastructure.

A cross-examination of the assessment modes uncovers a consistent 'cognitive ceiling' regarding written argumentation. Students demonstrated their lowest proficiency levels specifically in the essay test components for both Scientific Literacy (41.6%) and Action Competency (50.5%). This pattern indicates a systemic challenge in which students struggle to articulate their reasoning and action plans in a formal written format, despite demonstrating higher competence in practical observation or portfolio tasks (Permana et al., 2026) This finding underscores that the primary deficit may not lie entirely in the conceptual understanding of freshwater ecology, but rather in the academic skill of constructing scientific arguments and synthesizing ideas into coherent written responses (Evagorou et al., 2023; Suraya et al., 2019).

The substantial performance disparity between the two classes suggests that students' prior foundationa l knowledge may play a role in mastering socio-scientific issues. The superior performance of one group indicates that the processing of local issues like river pollution involves complex reasoning that may rely on earlier academic experiences (Sadler et al., 2016; Saija et al., 2022; Wisdayana et al., 2025). However, since no direct psychological measure of "cognitive readiness" was employed in this study, this interpretation should be approached with caution. Alternative factors, such as differences in class

dynamics, varying levels of student motivation, or subtle variations in instructional delivery prior to the study, could also account for the observed differences between the two classes.

The absence of a significant gender gap presents a promising insight into the inclusivity of the SSI approach. Unlike traditional STEM contexts where gender disparities often persist (Sagala et al., 2019), the use of local, contextually relevant issues rooted in the immediate ecological environment appears to level the playing field, engaging male and female students equally (Erman & Sari, 2019; Nasor et al., 2023; Permanasari et al., 2021; Rizal et al., 2019). This data suggests that when science is contextualized within the immediate environment, it resonates with diverse student groups regardless of gender, thereby serving as an equitable platform for fostering scientific literacy.

The dispersion of data, as indicated by the standard deviation, offers an additional layer of insight into student characteristics. The analysis reveals that the standard deviation for Action Competency (SD=7.11) is noticeably wider than that of Scientific Literacy (SD=5.87). This statistical variance suggests that while the students' cognitive grasp of ecological concepts is relatively uniform in its low proficiency, their capacity or willingness to act is far more heterogeneous. This broader distribution in action competency implies that non-cognitive factors, such as individual personality traits, confidence levels, or home environment, may play a more significant role in differentiating student performance in practical action than in theoretical understanding (Pratama et al., 2024; Suryawati et al., 2020).

Ultimately, these findings challenge the conventional Biology Education paradigm that prioritizes content mastery over functional application. The fact that students struggled most with the cognitive essay component of Action Competency indicates that they are not yet accustomed to synthesizing scientific knowledge about ecosystems to support a course of action. The educational implication is that future interventions must move beyond raising awareness to rigorously training students in the mechanics of action, specifically in how to debate, plan, and justify decisions based on data (Chen & Liu, 2020). Bridging the gap between the students' high self-perception and their lower actual competence requires a curriculum that provides repeated opportunities for simulated and real-world actions, allowing students to align their confidence with verifiable competence.

Despite the significant contributions of this study in diagnosing the knowing-doing gap within river ecosystem SSI, several limitations should be acknowledged. First, the use of a cross-sectional design does not allow for causal inferences regarding the instructional factors that led to the observed low proficiency levels. Second, the purposive sampling technique limits the generalizability of the findings to other junior high school populations. Future research in Biology Education should address these constraints by employing longitudinal or randomized controlled trial designs to test the efficacy of specific instructional interventions, such as the proposed Ecological Interactive E-Modules, in improving students' argumentative skills and closing the gap between perceived and actual action competency in real-world environmental settings.

D. Conclusion

This study concludes that there is a strong, positive, and significant association between scientific literacy and action competency in the context of ecological SSI. However, overall proficiency in both variables remains low, characterized by a critical "knowing-doing gap" in environmental action and a diagnostic discrepancy where high self-perception contradicts actual measured performance in solving river ecosystem issues. Furthermore, while the local SSI framework appears to be gender-inclusive, mastery levels remain sensitive to differences in initial academic abilities. These findings highlight that the current learning process may facilitate practical engagement but struggles to develop the linguistic and cognitive skills needed for formal ecological argumentation. Consequently, based on the interpretation of these diagnostic findings rather than direct experimental evidence, this study highlights the need for explicitly scaffolded pedagogical interventions. We hypothesize that developing adaptive learning materials, such as an Interactive E-Module based on local SSI, could serve as a potential solution to help students master the "mechanics of action". Future research should focus on the empirical design, implementation, and validation of such learning materials to test their actual efficacy, as well as on exploring the role of unmeasured non-cognitive variables, such as emotional intelligence, in driving sustainable environmental behavior.

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