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Environmental Awareness Based on Knowledge and Understanding: Thermodynamics Learning in the Context of Water Pollution in Forum Group Discussion (Fgd) Activities at Smas Sandikta, Bekasi City

Familia Novita Simanjuntak[1*], Bintang Simbolon[2], Alfa Graciani Kase[3], Yuliana Casria[4], Novita Veronica[5]
[134] Chemistry Education Study Program F, Faculty of Teacher Training and Education (FKIP), University Indonesian Christians
[2] Biology Education Study Program, Faculty of Teacher Training and Education (FKIP), Christian University of Indonesia
[5] Sandikta Senior High Schools in Bekasi
Corresponding Author: Familia Novita: familia.simanjuntak@uki.ac.id

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A B S T R A C T

This article includes the design, implementation, and results of a Focus Group Discussion (FGD) held at Sandikta Senior High School, Bekasi City, West Java, on May 20, 2026. The activity aimed to build students' environmental awareness by strengthening their knowledge and understanding of water pollution and its underlying scientific mechanisms through contextual thermodynamics learning, as a form of deep learning implementation at the secondary education level. Session I discussed the definition and sources of water pollution based on Law No. 32 of 2009, while Session II connected the First and Second Laws of Thermodynamics and Gibbs Free Energy with real-life water pollution phenomena. Kahoot! data from 60 participants in Quiz I and 60 participants in Quiz II were analyzed descriptively and quantitatively. Among the 47 students who took both quizzes, the average correct answer rate decreased from 6.49 to 3.74, a decrease of 42.3%. This FGD activity recommends strengthening collaboration between universities and secondary schools in designing contextual, problem-based environmental education programs that are oriented towards strengthening students' in-depth learning in secondary education.

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INTRODUCTION

Water pollution is one of the most pressing environmental challenges in Indonesia's rapidly growing urban areas. Bekasi City, a satellite city of Jakarta with a population of over three million, faces serious pressure from the discharge of industrial, agricultural, and domestic waste into water bodies. This situation makes Bekasi City a highly relevant laboratory for studying water pollution phenomena directly and contextually (BPS Bekasi City, 2023).

On the other hand, science instruction in high school often presents thermodynamics as a collection of abstract mathematical equations disconnected from the realities of students' everyday environments (Kurniawan & Sari, 2021). Yet, research consistently shows that contextual learning, which links abstract concepts to authentic problems in the surrounding environment, is more effective in building deeper understanding and increasing student motivation (Bransford et al., 2000; Sawyer, 2014).

Gamification-based quiz platforms like Kahoot! have been recognized as valid formative assessment tools in both formal and informal educational settings. Kahoot! increases student engagement through real-time scoring competitions and instant feedback, while generating useful diagnostic data for instructors to evaluate the effectiveness of a session's delivery (Dellos, 2015; Wang & Lieberoth, 2016).

Based on this background, the Chemistry Education and Biology Education Study Program, Faculty of Teacher Training and Education (FKIP), Indonesian Christian University (UKI) held a Focus Group Discussion (FGD) at Sandikta Senior High School, Bekasi City, on May 20, 2026. This activity aimed to: (1) build students' basic understanding of water pollution and its regulatory framework; (2) connect the laws of thermodynamics with observable water pollution phenomena; and (3) evaluate students' understanding through two Kahoot! quiz sessions that functioned as both ice breakers and formative assessments. This article presents the program design, implementation, and detailed quantitative analysis of the Kahoot! data from both sessions.

LITERATURE REVIEW

Deep Learning in Science Education

Deep learning is distinguished from surface learning by the process of actively constructing conceptual understanding, namely by integrating new information into existing knowledge structures, engaging in critical reflection, and applying concepts to new contexts (Marton & Säljo, 1976; Biggs & Tang, 2011). In science education, deep learning is operationalized through inquiry approaches, problem-based learning, and contextualizing abstract principles in real-world scenarios (Hmelo-Silver, 2004).

Thermodynamics is one of the most challenging domains for in-depth learning because its core concepts, such as entropy, free energy, and equilibrium, are non-intuitive and difficult to visualize (Carson & Watson, 2002). Research shows that students who learn thermodynamics contextually, for example through real-world phenomena, achieve a more stable understanding and are able to transfer the concepts to new situations than students who learn it solely through a mathematical-deductive approach.

Water Pollution: Regulatory and Scientific Framework

Legally, water pollution in Indonesia is defined in Law No. 32 of 2009 concerning Environmental Protection and Management, Article 1 Paragraph 14, as the entry or introduction of living creatures, substances, energy, and/or other components into water and water bodies by human activities, thereby exceeding established environmental quality standards. Scientifically, water quality is assessed through parameters including pH, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), nitrate, phosphate, and heavy metal concentrations (KLHK, 2020).

Bekasi City water quality data shows that major rivers such as the Bekasi River and the Cileungsi River chronically exceed BOD and COD thresholds, with DO concentrations frequently below 3 mg/L, a condition incompatible with the survival of most aquatic biodiversity (BPS Bekasi City, 2023). This situation makes Bekasi a highly illustrative case study for connecting scientific principles with community experiences.

Principles of Thermodynamics and Their Relation to Water Pollution

The application of the laws of thermodynamics to environmental chemistry provides a coherent mechanistic framework for understanding the behavior of pollutants in aquatic systems. The First Law of Thermodynamics, the conservation of energy, underlies the dynamics of thermal pollution: waste heat removed by industrial cooling systems increases water temperature and shifts the gas solubility equilibrium toward decreasing dissolved oxygen (DO) concentrations, a relationship quantified by the van 't Hoff equation (Atkins & de Paula, 2014). A drastic decrease in DO causes asphyxiation in aerobic aquatic organisms.

The Second Law of Thermodynamics, the universal tendency toward increasing entropy, explains the spontaneous diffusion of pollutants in water bodies. When concentrated effluent is discharged into a river, solutes spontaneously diffuse toward thermodynamic equilibrium (maximum entropy). This process is thermodynamically irreversible, meaning that remediation of dispersed pollutants requires a significant external energy input. This is the fundamental reason why the treatment of polluted water is technically demanding and economically expensive (Schwarzenbach et al., 2016).

The concept of Gibbs Free Energy (delta-G) further illuminates the spontaneity of the eutrophication process: algal biomass synthesis driven by fertilizer runoff, followed by aerobic decomposition (large negative delta-G), is a highly spontaneous series of reactions that systematically depletes dissolved oxygen, leading to anoxic conditions and the proliferation of anaerobic bacteria that produce the characteristic foul odor of severely polluted water bodies (Schwarzenbach et al., 2016).

Kahoot! as a Formative Assessment Tool

Kahoot! is a game-based learning platform that presents multiple-choice questions in a competitive, timed format accessible through personal devices. Its pedagogical utility in formal educational settings has been well documented.

Bicen and Kocakoyun (2018) demonstrated significant quiz score improvements in students using Kahoot! compared to conventional testing. Wang (2015) confirmed that the platform's competitive element, instant feedback, and the music-guided rhythm of the quizzes collectively maintained attention and reduced test anxiety. In the context of focus group discussions and non-formal education, Kahoot! serves a dual purpose: revitalizing participants between sessions (an icebreaker) and generating real-time diagnostic data on understanding, which was then exploited analytically in this study.

PROGRAM DESIGN AND IMPLEMENTATION METHODS

Location and Participants

The focus group discussion (FGD) was conducted at Sandikta Senior High School (SMA Sandikta), Bekasi City, West Java, Indonesia, on May 20, 2026. Sandikta Senior High School serves an urban student population in one of Indonesia's most active industrial areas. Participants were recruited from students present on the day of the program. A total of 60 students participated in the first Kahoot! session, and the same cohort of 60 students participated in the second Kahoot! session. No formal sampling criteria were applied; participation was voluntary and facilitated by the school.

Program Structure

The program is designed as two consecutive instructional sessions, each approximately 5 minutes long , separated by a short break. Each session is immediately followed by a 10-question Kahoot! quiz. The program flow is as follows:

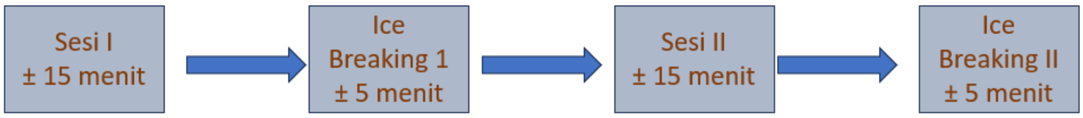

Figure 1. FGD Program Timeline

Session I: Water Pollution - Fundamentals and Regulatory Framework

Session I was delivered by a lecturer from the Biology Education Study Program, Mrs. Dr. Bintang Simbolon, M.Si, UKI. The session opened with contextual data regarding access to clean water and river water quality in Bekasi City, placing the scientific content in the context of students' direct environmental experiences. Core topics discussed included: (a) the legal definition of water pollution based on Law No. 32/2009; (b) the main sources of water pollution including industrial waste, agricultural runoff, domestic waste, and solid waste leachate; (c) water quality indicators and their ecological thresholds; and (d) documented impacts on public health and biodiversity in the Bekasi watershed. The session was complemented by an interactive Q&A to maintain participant engagement and activate their prior knowledge.

Figure 2. Documentation of activities (presentation of session 1 material)

a) Ice Breaking I: Kahoot Quiz! I

Immediately following Session I, participants took a 10-question Kahoot! quiz titled Smart Quiz: Water Pollution & Environmental Health. The questions assessed understanding of water pollution regulatory definitions, identification of pollution sources, understanding of water quality parameters, and awareness of health impacts. All 60 participants competed simultaneously using their smartphones. The platform automatically recorded individual scores, the number of correct answers, and overall session statistics.

Figure 3. Activity documentation (ice breaking session 1 directions)

Session II: Laws of Thermodynamics and Dynamics of Water Pollution

Session II was delivered by Dr. Familia Novita Simanjuntak, SP, M.Si, UKI, a lecturer from the Chemistry Education Study Program. Building on the pollution foundation established in Session I, this session introduced the principles of thermodynamics as an analytical tool for understanding pollutant behavior. The session was organized around three conceptual pillars: (a) The First Law of Thermodynamics, namely thermal pollution, the inverse relationship between water temperature and dissolved oxygen, and its ecological consequences; (b) The Second Law of Thermodynamics, namely entropy as a driver of spontaneous pollutant dispersal and the thermodynamic basis for the high cost of water remediation; and (c) Gibbs Free Energy (delta-G), namely the spontaneity of eutrophication reactions, aerobic decomposition, and the progression towards anoxic conditions. Concrete local examples, including fish kills and the blackening of rivers that occurred in Bekasi, were used to connect each theoretical concept with realities that students could observe.

Figure 4. Implementation of activities (Presentation of session II material)

Ice Breaking II: Kahoot Quiz! II

The program concluded with a 10-question Kahoot! quiz titled "Water Thermal Pollution & Ecosystem Dynamics," which targeted understanding of the thermodynamic content from Session II. The questions assessed understanding of thermal pollution mechanisms, entropy-based diffusion, Gibbs Free Energy and reaction spontaneity, eutrophication dynamics, and the formation of anoxic conditions. All 60 participants from the same cohort participated in this session.

Figure 5. Activity documentation (Implementation of ice breaking session II)

Data analysis

Kahoot! results data from both quizzes were exported in Microsoft Excel (.xlsx) format and analyzed using Python (pandas library). Descriptive statistics calculated for each quiz included: number of participants (n), mean and median correct answers (out of 10 questions), mean and median total score (points), correct answer rate (%), and frequency distribution of the number of correct answers. Participants' performance was further classified into three competency categories: High (>= 8 correct), Medium (5-7 correct), and Low (<5 correct). For 47 students identifiable by username in both quizzes, a pairwise analysis was conducted to determine changes in individual scores between sessions.

RESULTS

Overview: Performance Comparison of Two Kahoot! Sessions

Table 1 presents a consolidated summary of performance indicators for Quiz I and Quiz II. The data show substantial divergence between the two sessions, with the correct answer rate decreasing from 61.33% in Quiz I to 39.44% in Quiz II, a difference of 21.89 percentage points. The average score also decreased from 7,235 to 3,584 points. This pattern confirms that the content of Session II presented a significantly greater cognitive challenge for participants.

Table 1. Comparative Summary of Quiz I and Quiz II Performance (n = 60)

Parameter	Quiz I Water Pollution & Environmental Health	Quiz II: Thermal Water Pollution & Ecosystem Dynamics
Implementation date	May 20, 2026	May 20, 2026
Number of participants	60 students	60 students
Number of Questions	10 questions	10 questions
Average Correct Answer	6.13 / 10	3.55 / 10
Percentage of Correct Answers	61.33%	39.44%
Average Score (points)	7,235	3,584
Median Score (points)	8,100	3,450
Highest Score	10,765	10,659
High Category (>= 8 correct)	20 students (33.3%)	4 students (6.7%)
Medium Category (5-7 correct)	31 students (51.7%)	13 students (21.7%)
Low Category (< 5 correct)	9 students (15.0%)	43 students (71.7%)

Frequency Distribution of Correct Answers

Table 2 presents the complete frequency distribution of the number of correct answers (0-10) on both quizzes. In Quiz I, the distribution was concentrated in the upper range: 19 students (19.8%) answered exactly 9 questions correctly, and 20 students (20.8%) answered 7 questions correctly. In contrast, Quiz II showed a distribution that was strongly skewed to the left, with 12 students (20.0%) answering only 2 questions correctly and 11 students (18.3%) answering 3 questions correctly. No student achieved a perfect score (10/10) on either quiz.

Table 2. Frequency Distribution of Correct Answers - Quiz I and Quiz II (n = 60)

Correct Amount	Quiz I (n)	Quiz I (%)	Quiz II (n)	Quiz II (%)
0	6	10.0%	5	8.3%
1	2	3.3%	5	8.3%
2	0	0.0%	12	20.0%
3	0	0.0%	11	18.3%
4	1	1.7%	10	16.7%
5	8	13.3%	6	10.0%
6	11	18.3%	2	3.3%
7	12	20.0%	5	8.3%
8	8	13.3%	2	3.3%
9	12	20.0%	2	3.3%
10	0	0.0%	0	0.0%
Total	60	100%	60	100%

a. Competency Category Analysis

Classifying participants into three competency categories provides a clearer picture of the shift in distribution between sessions. In Quiz I, most participants were in the High (33.3%) or Medium (51.7%) categories, with only 15.0% in the Low category. In Quiz II, this profile reversed dramatically: 71.7% of participants were in the Low category, only 21.7% in the Medium category, and only 6.7% in the High category. This reversal is a central empirical finding of this study and directly points to the increased cognitive complexity of thermodynamics content compared to descriptive knowledge of water pollution.

b. Pairwise Analysis of 47 Students Who Attended Both Sessions

Matching usernames across both datasets identified 47 students who participated in both Quiz I and Quiz II. Table 3 presents pairwise performance statistics for this cohort.

Table 3. Pairwise Comparison of Performance of Students Who Attended Both Quiz Sessions (n = 47)

Indicator	Quiz I	Quiz II	Difference
Number of Students Identified	47 students	47 students	—
Average Correct Answer	6.49	3.74	-2.74 questions (-42.3%)
Students who Improve	—	7 students (14.9%)	+
Students with Fixed Scores	—	3 students (6.4%)	=
Students Who Decline	—	37 students (78.7%)	-

In the matched cohort, the average correct answer decreased from 6.49 on Quiz I to 3.74 on Quiz II, a reduction of 2.74 questions or a decrease in average accuracy of 42.3%. Only 7 students (14.9%) improved their scores on Quiz II, 3 students (6.4%) maintained the same score, and 37 students (78.7%) experienced a decrease in their scores. The magnitude and direction of this pattern confirm that the decline in performance was not due to random variation but rather reflected the substantially greater conceptual demands of the content of Quiz II.

Interestingly, the student with the highest Quiz I score (9 correct answers, 10,765 points) recorded 0 correct answers on Quiz II, while the student with the highest Quiz II score (9 correct answers, 10,659 points) had also performed well on Quiz I (9 correct answers, 9,870 points). This indicates that strong performance on Quiz I does not consistently predict performance on Quiz II.

Item Analysis: Quiz I – Water Pollution & Environmental Health

Quiz I was held on May 21, 2026, with 60 participants and consisted of 10 questions: 1 opinion poll, 7 multiple-choice quizzes, and 2 true-false questions. Of the 10 questions, only 1 was categorized as difficult. Table 4 presents details of each question, along with the correct answer level and explanations.

Table 4. Analysis of Quiz I Question Items – Water Pollution & Environmental Health (n = 60)

No.	Question	Type of Question	True/False	Question Description
1	How often do you think about clean water?	Opinion poll	–	
2	What does urban water pollution mean?	Quiz	74%	
3	Where are the common sources of household pollutants found?	Quiz	31%	Difficult question
4	Is this statement true or false: The textile and dyeing industries interfere with the photosynthesis of aquatic plants?	True or false	79%	
5	Why is polluted water dangerous for health?	Quiz	88%	
6	How can communities prevent pollution?	Quiz	43%	
7	When is water considered drinkable?	Quiz	81%	
8	Who is responsible for processing industrial waste?	Quiz	53%	
9	The following image shows what groundwater sources?	True or false	85%	
10	What are the impacts of untreated effluent?	Quiz	84%	

Item Analysis: Quiz II – Thermal Water Pollution & Ecosystem Dynamics

Quiz II was held on May 21, 2026, with 60 participants and consisted of 10 questions, including 1 opinion poll, 7 multiple-choice questions, and 2 true-false questions. Of the 10 questions, 6 were categorized as difficult. All 9 quiz questions (nos. 2–10, excluding poll no. 1) form the basis for the analysis of students' environmental awareness in this article. Table 5 presents details of each question along with the level of correct answers and their explanations.

Table 5. Analysis of Quiz II Question Items: Water Thermal Pollution & Ecosystem Dynamics (n = 60)

No.	Question	Type of Question	True/False	Question Description
1	How familiar are you with thermal water pollution?	Opinion poll	–	
2	What happens when the water temperature rises?	Quiz	28%	Difficult question
3	Why does oxygen solubility decrease when it is hot?	Quiz	38%	Difficult question
4	Is this statement true or false: Higher temperatures increase an organism's oxygen requirements?	True or false	82%	
5	What are the consequences of severe dissolved oxygen deficiency?	Quiz	32%	Difficult question
6	Why do pollutants spread quickly in rivers?	Quiz	52%	
7	Is this statement true or false: Water purification is thermodynamically spontaneous?	True or false	37%	Difficult question

No.	Question	Type of Question	True/False	Question Description
8	What determines the spontaneity of water reactions?	Quiz	33%	Difficult question
9	Why do algae explode when fertilizer is added?	Quiz	10%	Difficult question
10	What do bacteria do to organic waste?	Quiz	43%	

The data from Tables 4 and 5 illustrate two distinct environmental awareness profiles. In Quiz I, 7 of the 9 quiz items were answered correctly by more than 50% of students, reflecting a well-established basic knowledge of water pollution. In Quiz II, only 2 of the 9 quiz items (question no. 4 with 82% and question no. 6 with 52%) exceeded the 50% threshold, while the other 7 items fell below 50%, with a range of 10%–43%. This pattern forms the basis for discussing the extent to which understanding thermodynamic concepts has supported the development of a more comprehensive environmental awareness in students.

DISCUSSION

From Knowledge to Environmental Awareness: The Challenge of Understanding Water Pollution Mechanisms

The 29.31 percentage point gap in correct answer rates between Quiz I and Quiz II is best understood through the distinction between declarative knowledge (knowing that) and conceptual knowledge (knowing why and how). The content of Session I, consisting of definitions, classifications, and regulatory standards, primarily demands declarative recall, a less demanding cognitive operation that students can access through general awareness and contextual familiarity (Anderson & Krathwohl, 2001). The content of Session II, in contrast, requires students to reason with abstract principles such as entropy and free energy and then apply them to novel environmental scenarios, a higher-order cognitive operation that falls under the Analysis, Evaluation, and Application categories of Bloom's Taxonomy (Krathwohl, 2002).

The 78.7% attrition rate among matched students confirms that this is not simply a matter of fatigue, distraction, or differences in effort, but rather a real epistemological challenge posed by thermodynamic reasoning. This finding aligns with Carson and Watson's (2002) characterization of thermodynamics as one of the most difficult topics in physics, as well as with Sozbilic's (2003) finding that secondary students generally have persistent misconceptions about entropy and spontaneity.

Kahoot! as an Initial Mapping of Student Knowledge and Understanding

Kahoot! in this activity serves a simple yet important function: as an interactive poll and quiz that quickly maps students' knowledge and understanding of the newly presented material. As a game-based learning platform, Kahoot! allows all participants to answer simultaneously using their respective devices, allowing the results to be immediately read as a snapshot of the class's current understanding (Dellos, 2015). This snapshot then serves as the starting point for the discussion in this article, not to evaluate the platform, but rather to read what students actually understand and are aware of regarding the issues of water pollution and environmental thermodynamics.

Environmental Awareness in Session I: Between Concern and Conceptual Understanding

Quiz I opened with a survey item asking how often students thought about clean water issues, before moving on to nine quiz items on the definition, sources, indicators, and impacts of water pollution. The results revealed an interesting pattern: students generally had relatively good environmental awareness, especially in aspects that affect their daily lives and health. Eighty-eight percent of students correctly answered the question about why polluted water is dangerous to health, and 84% correctly answered the question about the impact of discharging untreated liquid waste (effluent) into water bodies. This achievement indicates that awareness of the risks of water pollution to health and the environment is quite ingrained, in line with the finding that ecological knowledge is one of the main pillars of environmental literacy alongside attitudes and behavior (McBeth & Volk, 2009 in Cahyani et al., 2025).

However, a clear gap was also found between general awareness and more specific conceptual understanding. The most difficult item on Quiz I, with a correct answer rate of only 31%, was about common household pollutant sources found in everyday environments. Meanwhile, the question about how communities can prevent water pollution was answered correctly by only 43% of students, and the question about the parties responsible for processing industrial waste was answered correctly by only 53%. This pattern indicates that students tend to readily recognize that water pollution is dangerous (affective awareness), but do not fully understand where the sources of pollution come from and what concrete steps they and the community can take to prevent it (cognitive and behavioral understanding). These findings align with studies of environmental literacy in Indonesia, which generally show fairly good basic knowledge, but still weak cognitive skills and pro-environmental behavior (Putra et al., 2021).

This pattern is also consistent with the finding that general environmental knowledge is often widely held by students and the community, but specific environmental knowledge, namely technical understanding of the sources, mechanisms, and methods of handling pollution, is actually a more determining factor in the formation of real pro-environmental behavior (Burgos-Espinoza et al., 2024). In other words, students' environmental awareness in Session I was already sufficiently developed in terms of concern, but still needed strengthening in terms of technical understanding so that this awareness could be translated into concrete attitudes and actions in maintaining the cleanliness of the water in their environment.

a. Environmental Awareness in Session II: When Understanding Mechanisms Becomes a Challenge

In Quiz II, of the 9 quiz items (excluding the poll), only 2 items were answered correctly by more than half of the participants, namely question no. 4 regarding the relationship between temperature and the oxygen needs of organisms (82%) and question no. 6 regarding why pollutants spread quickly in rivers (52%). The remaining 7 of the 9 items were below the 50% threshold, with the following details: question no. 2 regarding what happens when water temperature rises (28%), question no. 3 regarding why oxygen solubility decreases when it is hot (38%), question no. 5 regarding the effects of severe dissolved oxygen deficiency (32%), question no. 7 regarding whether water purification is thermodynamically spontaneous (37%), question no. 8 regarding what determines the spontaneity of water reactions (33%), question no. 9 regarding why algae explode when fertilizer is added (10%), and question no. 10 regarding what bacteria do to organic waste (43%). This pattern as a whole shows that students do not fully understand the cause-and-effect sequence behind the phenomenon of thermal water pollution that they can actually observe in their surroundings, such as rivers that are black, smelly, or filled with dead fish.

Interestingly, one true-false item regarding the relationship between higher water temperatures and the oxygen needs of aquatic organisms was answered correctly by 82% of students, significantly higher than other items in the same session. This indicates that students are able to grasp the symptoms or end results of an environmental phenomenon, but have difficulty when asked to explain the mechanisms or reasons behind these symptoms. Thus, the gap in Session II lies not in awareness that the phenomenon occurs, but in understanding why and how it occurs, a type of understanding that aligns with the ecological knowledge component of the environmental literacy framework (Hollweg et al., 2011; McBeth & Volk, 2009).

These findings are relevant to the results of environmental literacy studies on secondary school students in Indonesia, which generally show moderate achievement with a similar pattern, namely relatively good basic knowledge and caring attitudes, but cognitive skills to analyze the mechanisms of environmental problems still need to be improved (Cahyani et al., 2025). For this FGD activity, these findings provide a clear roadmap: strengthening the understanding of the thermodynamic mechanisms behind pollution phenomena, such as the temperature-oxygen relationship, pollutant distribution, and eutrophication, will be an important lever to shift students' environmental awareness from simply "knowing that polluted rivers are bad" to "understanding why rivers can be polluted and how to prevent it."

b. From Knowledge to Care: Building a Comprehensive Environmental Awareness

Overall, the data from both sessions illustrated a profile of students' environmental awareness that still relies on superficial knowledge and affective attitudes, but is not yet balanced by an adequate conceptual understanding of the sources, mechanisms, and efforts to address water pollution. This condition aligns with environmental literacy studies at various levels of education in Indonesia, which consistently find that knowledge and attitudes tend to be in the good category, while cognitive skills and pro-environmental behavior remain in the moderate category (Putra et al., 2021; Cahyani et al., 2025).

This is important to note because good environmental knowledge does not automatically translate into environmentally conscious behavior unless students truly understand the connection between the concepts learned and the real consequences in their environment (Hines et al., 1987). In other words, strong environmental awareness can only grow if scientific knowledge, such as the laws of thermodynamics discussed in Session II, is truly understood as an explanation of the water pollution phenomena they can observe themselves in Bekasi City, such as blackened, smelly rivers, or sudden fish deaths. This kind of understanding will change students' perception of water pollution from merely an abstract issue to a real problem directly related to their lives.

Therefore, similar FGD activities in the future should not stop at conveying definitions and basic laws, but explicitly link each concept to reflective questions such as: what can I do about the sources of pollution in my home environment, and why the phenomena I see in the river near school can be explained by the principles of thermodynamics that have just been learned. This kind of contextual approach is also in line with Sustainable Development Goals (SDGs) Number 4 (Quality Education) and Number 6 (Clean Water and Sanitation), because ultimately the goal of environmental education is not just to make students know, but to make students aware and motivated to participate in maintaining the quality of water in the environment where they live.

CONCLUSION

This study has demonstrated that structured and contextualized focus group discussions (FGDs), integrating thermodynamics learning with the realities of local water pollution, effectively engage high school students and stimulate meaningful scientific inquiry. Kahoot!-based formative assessment data, covering 60 participants in Quiz I and 60 participants in Quiz II, provide strong quantitative evidence of the program's strengths as well as areas for pedagogical improvement.

Quiz I achieved a 61.33% correct answer rate, with 85.0% of participants falling in the Medium to High competency category, indicating that students' environmental awareness of water pollution has begun to develop at the basic awareness and knowledge level. Quiz II recorded a 39.44% correct answer rate, with 71.7% of participants falling in the Low category, indicating that students' understanding of the scientific mechanisms behind water pollution phenomena, such as thermal pollution, dissolved oxygen depletion, and eutrophication, still needs to be strengthened. Among the 47 students who participated in both sessions, the average accuracy decreased by 42.3%, further confirming that strong environmental awareness can only develop when students have a thorough understanding of the scientific mechanisms. These findings indicate that students' environmental awareness has begun to develop at the awareness level of water pollution, but still need to strengthen their knowledge and understanding of the scientific mechanisms so that this awareness can develop into more concrete pro-environmental attitudes and behaviors.

These findings have practical implications for the design of subsequent FGD activities: contextualization and gamification are effective engagement strategies for fostering students' initial awareness, but they must be combined with more intensive reinforcement of understanding of scientific mechanisms so that students' environmental awareness truly develops into pro-environmental attitudes and behaviors, rather than simply knowing that pollution is dangerous. The program model pioneered here, integrating university expertise, community environmental relevance, and real-time formative assessment technology, offers a transferable template for environmental education activities in high schools in rapidly growing Indonesian cities.

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AUTHOR CONTRIBUTION

All authors listed contributed to the program's design and development, delivery of instructional sessions, data collection, analysis, and drafting of the manuscript. All authors reviewed and approved the final manuscript.

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