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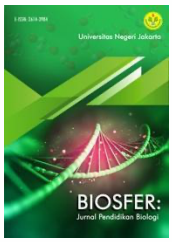

Microorganism knowledge and hygiene behavior among senior high school students

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ABSTRACT

Public understanding of microorganisms is a critical component of scientific literacy, particularly in the context of infectious disease prevention. However, research consistently documents persistent misconceptions and fragmented knowledge among secondary school students, underscoring the need for evidence-based evaluation of microbiology literacy in formal education settings. This study aimed to evaluate the levels of knowledge, attitudes, perceptions, and behaviors of senior high school students regarding microorganism-related issues within a biology education context. A cross-sectional survey design was employed involving 188 eleventh- and twelfth-grade students from senior high schools in Tuban Regency, East Java, Indonesia. Data were collected using a structured questionnaire encompassing four dimensions: knowledge (6 Likert-scale items), attitudes (6 Likert-scale items), perceptions (7 multiple-choice items), and behaviors (7 multiple-choice items), and were analyzed descriptively. Results revealed that students' knowledge was categorized as high (mean = 3.15). However, conceptual understanding remained fragmented, with students predominantly perceiving microorganisms as harmful agents. Perceptions fell within the moderate category, reflecting a gap between factual knowledge and integrated scientific understanding. Attitudes were very high overall (mean = 3.48), though inconsistencies were evident in food safety decision-making. Hygiene-related behaviors were generally high; however, discrepancies were observed in food storage practices and disinfectant use. These findings indicate that strong basic knowledge and positive attitudes do not automatically translate into consistent and appropriate health behaviors. Biology education programs must therefore adopt integrative instructional approaches that explicitly connect microbiological concepts with real-world applications to bridge knowledge-attitude-behavior gaps and promote health-literate graduates.

INTRODUCTION

Microbiology literacy has emerged as a foundational component of scientific citizenship, as understanding of microorganisms is essential for informed decision-making in health, food safety, and disease prevention (Timmis et al., 2019). The role of education in shaping such literacy is well established: school-based biology instruction provides students with their primary framework for understanding microbial diversity, ecology, and function (Simard, 2023). Despite this, research conducted across diverse educational contexts consistently documents the persistence of misconceptions and oversimplifications regarding microorganisms, particularly the tendency to categorize all microbes as pathogens (Lane et al., 2025; Ruiz-Gallardo & Paños, 2018). These conceptual gaps are not merely academic; they have direct consequences for public health literacy and preventive behaviors.

The relevance of microbiological knowledge has been amplified by the COVID-19 pandemic, which demonstrated how knowledge, attitudes, and perceptions toward microbes directly influence preventive behaviors, including hand hygiene, mask use, physical distancing, and vaccine uptake (Panahi et al., 2024). Research within the Knowledge, Attitude, and Practice (KAP) framework has shown that knowledge alone is insufficient to sustain behavioral change; rather, attitudes and perceptions serve as critical mediators between knowledge acquisition and health-protective action (Zarei et al., 2024). Among adolescents, who are at a formative stage of scientific reasoning and identity development, educational experiences play a particularly influential role in shaping these mediating constructs (Bhave & Yadav, 2015).

Existing studies examining microbiological knowledge among secondary school students report patterns of fragmented understanding. Students frequently demonstrate contextually accurate knowledge, for example, recognizing the role of microorganisms in fermentation while simultaneously holding misconceptions regarding the predominantly beneficial nature of microbial life (Fidiastuti et al., 2024; Fonseca de Fraga, 2019). Studies by Byrne (2011) and Simard (2023) found that most respondents had a limited understanding of the beneficial roles of microorganisms and that negative associations predominate. Karadon & Şahin (2010) reported that 53% of elementary school students perceived microorganisms as harmful, and 37.4% could not identify any microorganism by name. These patterns persist into secondary schooling and are reinforced by curriculum designs that disproportionately emphasize pathogenic over beneficial microorganisms (Ruiz-Gallardo & Paños, 2018). However, these prior studies were largely conducted at the primary level or in urban and Western educational settings, and most examined only one or two dimensions of microbiological literacy in isolation. The present study extends this body of work by simultaneously profiling all four KAP dimensions among senior high school students in a non-urban context, thereby revealing not merely whether misconceptions persist but how knowledge, attitudes, perceptions, and behaviors interact and diverge within the same population.

The consequences of low microbiological literacy extend beyond individual misconceptions. Negative perceptions of microorganisms have been associated with germaphobia, excessive disinfectant use, antibiotic misuse, and resistance to vaccines all of which carry significant public health implications (Bhat et al., 2022; Robinson et al., 2021). The interplay between knowledge, attitudes, and behavior within the KAP framework suggests that addressing misconceptions requires more than content delivery; it necessitates targeted instructional strategies that reshape attitudes and build adaptive behaviors (Hapsari & Jaksa, 2025).

This study was deliberately conducted in Tuban Regency, a coastal district in northern East Java, Indonesia. Tuban is most accurately characterized as a non-urban, peri-urban (suburban) area: although it contains a modest administrative town center, the majority of its territory comprises agricultural, coastal, and semi-rural communities with comparatively limited access to advanced laboratory facilities, health-promotion infrastructure, and science-enrichment resources of the kind available in metropolitan centers such as Surabaya. This setting is scientifically meaningful because most existing microbiology-literacy research has been conducted in urban or higher-resource contexts, leaving suburban and non-urban student populations substantially underrepresented. Evaluating microbiological knowledge, attitudes, perceptions, and behaviors in such a setting therefore aligns directly with the journal's expanded scope encompassing urban and non-urban biology education, and it helps clarify how educational context shapes scientific literacy. Moreover, Tuban students are embedded within a strong local Javanese cultural milieu, in which everyday practices surrounding food

(for example, traditional fermented products such as tempeh and other home-processed foods), hygiene, and health are mediated by community traditions and local knowledge. These sociocultural characteristics are likely to shape how students perceive and act upon microorganisms, making this population a valuable and previously underexamined context for assessing microbiology literacy.

Despite the growing body of evidence documenting microbiological misconceptions, comprehensive empirical assessments of all four KAP dimensions simultaneously, knowledge, attitudes, perceptions, and behaviors, remain scarce among Indonesian high school students, a population that has received limited scholarly attention in this domain. The present study addresses this gap by providing a cross-sectional, multi-dimensional evaluation of these constructs. The novelty of this study lies in its simultaneous measurement of four KAP dimensions in a non-urban Indonesian secondary school context, with direct implications for the design of biology education curricula. Understanding the current profile of students' microbiological KAP is both urgent and strategically important: it enables educators to identify specific misconceptions and behavioral inconsistencies, design evidence-based instructional interventions, and contribute to the development of scientifically literate citizens equipped for health-related decision-making. The central research question guiding this study is: What are the levels of knowledge, attitudes, perceptions, and behaviors of senior high school students toward microorganism-related issues, and what are the implications for biology education?

METHODS

Research Design and Participants

This study employed a cross-sectional survey design, which is appropriate for describing the characteristics of a population at a single point in time and for identifying associations among variables without experimental manipulation (Creswell, 2011). The study population comprised all eleventh- and twelfth-grade students enrolled in senior high schools in Tuban Regency, East Java, Indonesia, during the 2024–2025 academic year. A purposive sampling approach was used to select 188 students from schools accessible to the research team, ensuring adequate representation of both grade levels and gender. Participant characteristics are summarized in Table 1. Prior to participation, all students received a written informed consent form detailing the study objectives, data confidentiality, and the voluntary nature of participation. No academic consequences were associated with participation or non-participation.

Table 1.
Demographic and General Characteristics of Participants

Characteristic	Category	n	%
Gender	Male	69	36.70
	Female	119	63.30
Age	16 years	104	55.32
	17 years	82	43.62
	18 years	2	1.06
Education Level	Senior High School	188	100
Occupation	Student	188	100
Total		188	100

Note. All participants were active senior high school students in Tuban Regency, East Java, Indonesia

Research Instrument and Data Collection

The research instrument was developed as a structured questionnaire, adapted from previously validated cross-sectional survey tools examining microbiological knowledge, attitudes, and practices (Abu-Humaidan et al., 2021; DeSalle et al., 2022; Sawan et al., 2024). The instrument comprised four sections corresponding to the four KAP dimensions. Knowledge was assessed using six Likert-scale items targeting conceptual understanding of the roles of microorganisms, fermentation, hygiene, and sterilization. Attitudes were assessed using six five-point Likert-scale statements capturing students' attitudinal orientations toward microorganism-related health, food safety, and disease prevention behaviors. Perceptions and behaviors were each assessed using seven multiple-choice items. The detailed structure of the instrument is presented in Table 2.

Table 2.
Survey Indicators, Item Distribution, and Scoring Scheme

Indicator	Aspect Assessed	Question Type	Items (n)	Scoring System
Knowledge	Basic concepts, roles, benefits, and environmental impacts of microorganisms	Likert scale	6	SA=5, A=4, N=3, D=2, SD=1
Perception	Respondents' views and interpretations of microorganisms	Multiple choice	7	Correct=1; Incorrect=0
Attitudes	Views toward microorganisms related to health, hygiene, food safety, and disease prevention	Likert scale	6	SA=5, A=4, N=3, D=2, SD=1
Behaviors	Application of knowledge and attitudes in everyday life practices	Multiple choice	7	Correct=1; Incorrect=0

Note. SA = Strongly Agree; A = Agree; N = Neutral; D = Disagree; SD = Strongly Disagree. Adapted from Abu-Humaidan et al. (2021), DeSalle et al. (2022), and Sawan et al. (2024).

Content validity was established through expert review by two subject-matter specialists in biology education and microbiology, who evaluated item relevance, clarity, and alignment with the study objectives. Item-level validity was assessed using Pearson product-moment correlation ($r > 0.30$ as the threshold for item retention). Internal consistency reliability was evaluated using Cronbach's alpha, yielding coefficients of $\alpha = 0.78$ for the Knowledge subscale and $\alpha = 0.81$ for the Attitudes subscale, indicating acceptable to good reliability (George & Mallery, 2003). Data were collected via Google Forms administered directly to students in classrooms between May and June 2025.

Data Analysis

Data were analyzed descriptively. Demographic characteristics are reported as frequencies and percentages. Knowledge and attitude scores were calculated as the mean of Likert-scale items and categorized according to the criteria established by Mustofa and Sueb (2023): Very High (≥3.21), High (2.41–3.20), Medium (1.61–2.40), and Low (≤0.81–1.60). Perception and behavior data, derived from multiple-choice responses, were analyzed as percentage scores of correct or dominant responses and categorized following Mustofa et al. (2021): Very High (85–100%), High (70–84.9%), Medium (55–69.9%), Low (40–54.9%), and Very Low (25–39.9%). The categorization criteria and analysis procedures for each variable are presented in Table 3.

Table 3.
Data Analysis Techniques and Categorization Criteria

Variable	Data Type	Analysis Technique	Scale or Score	Category Criteria
Demographics	Nominal	Frequencies & percentages	Nominal	—
Knowledge	Cognitive	Mean score from Likert responses	Likert 1–5	VH ≥3.21; H 2.41–3.20; M 1.61–2.40; L ≤1.60 (Mustofa & Sueb, 2023)
Perceptions	Perceptual	% dominant responses	Correct=1; Incorrect=0	VH 85–100%; H 70–84.9%; M 55–69.9%; L 40–54.9%; VL 25–39.9% (Mustofa et al., 2021)
Attitudes	Affective	Mean score from Likert responses	Likert 1–5	VH ≥3.21; H 2.41–3.20; M 1.61–2.40; L ≤1.60 (Mustofa & Sueb, 2023)
Behaviors	Practical	% dominant responses	Correct=1; Incorrect=0	VH 85–100%; H 70–84.9%; M 55–69.9%; L 40–54.9%; VL 25–39.9% (Mustofa et al., 2021)

Note. VH = Very High; H = High; M = Medium; L = Low; VL = Very Low.

RESULTS AND DISCUSSION

Knowledge of Microorganisms

Students' knowledge of microorganisms was assessed across six Likert-scale items targeting conceptual and applied dimensions. As presented in Table 4, mean scores across individual items ranged from 2.42 to 3.30, with the overall knowledge profile spanning the High to Very High categories. These findings indicate that students possess a functional foundation of microbiological knowledge, particularly in relation to applied, everyday contexts such as fermentation and hygiene.

Table 4.
Knowledge Scores Across Survey Items (n = 188)

No.	Statement	SD (1)	D (2)	N (3)	A (4)	SA (5)	Mean	Category
1.	Microorganisms are found in dairy products such as yogurt.	1 (0.53%)	7 (3.72%)	37 (19.68%)	59 (31.38%)	83 (44.15%)	3.30	Very High
2.	Mobile phone keypads contain bacteria comparable to toilet seats.	15 (7.98%)	24 (12.77%)	60 (31.91%)	44 (23.40%)	55 (29.26%)	2.95	High
3.	Bread dough rises due to microorganism activity.	6 (3.19%)	8 (4.26%)	37 (19.68%)	59 (31.38%)	77 (40.96%)	3.21	Very High
4.	Bacteria are organisms generally harmful to human health.	15 (7.98%)	39 (20.74%)	70 (37.23%)	43 (22.87%)	19 (10.11%)	2.42	High
5.	Most bacteria are found on money.	4 (2.13%)	13 (6.91%)	37 (19.68%)	82 (43.62%)	51 (27.13%)	3.08	High
6.	Sterilization eliminates more than 99% of microorganisms.	14 (7.45%)	13 (6.91%)	43 (22.87%)	61 (32.45%)	55 (29.26%)	2.93	High
	Overall Mean						3.15	High

Note. SD = Strongly Disagree; D = Disagree; N = Neutral; A = Agree; SA = Strongly Agree. Categorization criteria adapted from Mustofa and Sueb (2023).

The highest mean score was recorded for Item 1 (M = 3.30, Very High), which assessed awareness of microorganisms in fermented dairy products, and Item 3 (M = 3.21, Very High), related to the role of microorganisms in bread leavening. These results are consistent with prior findings indicating that students more readily comprehend microbiological concepts when they are contextualized within familiar, everyday experiences (Krause et al., 2016; Nagashima, 2018). Similarly, a study on proportional reasoning found that even brief contextual experiences significantly enhanced students' ability to apply learned concepts to realistic problems (Matney et al., 2013). In contrast, Item 4 which assessed whether bacteria are generally harmful to human health yielded the lowest mean score (M = 2.42, High) and the most ambiguous response distribution: 32.98% of students agreed or strongly agreed, 28.72% disagreed or strongly disagreed, and 37.23% selected a neutral response. This pattern is theoretically significant. Rather than reflecting a simple knowledge deficit, it indicates a state of conceptual disequilibrium. Disequilibrium is a natural part of learning, as it prompts students to process new information to restore cognitive balance. This aligns with Piaget's theory, which suggests that disequilibrium triggers efforts to integrate new knowledge into existing cognitive structures (Hanke, 2010; Sarirete et al., 2009, 2010).

The high proportion of neutral responses suggests that students recognize some nuance that not all bacteria are harmful but have not yet developed a coherent understanding of microbial diversity and the predominance of non-pathogenic species. This finding aligns with Simard's (2023)observation that formal biology instruction often fails to effectively challenge the pathogenic framing of bacteria that students develop through everyday media and lived experience. Many students associate bacteria primarily with disease, overlooking their beneficial roles in processes such as food production, environmental sustainability, and human health (Fatton et al., 2021). Misconceptions are deeply rooted in intuitive reasoning and worldviews, making it difficult for students to reconcile new scientific information with pre-existing beliefs (Pickett et al., 2022; Reiss, 2018). Misconceptions persist due to incomplete or incorrect conceptual frameworks developed from everyday experiences or insufficient education. These misconceptions are resistant to change unless explicitly addressed through targeted interventions. The persistence of this misconception across age groups and educational levels underscores its resilience and the need for targeted instructional strategies that explicitly contrast pathogenic and beneficial bacterial roles within ecologically meaningful contexts (Cañada et al., 2017; Herak et al., 2025).

Perceptions of Microorganisms

Students' perceptions of microorganisms were assessed using seven multiple-choice items

designed to capture dominant conceptual associations and behavioral attitudes. As shown in Table 5, perception scores ranged from the Low to Very High categories, indicating considerable variation across items.

Table 5.
Students' Perceptions of Microorganisms (n = 188)

No.	Question	Most Selected Option	n	%	Category
1.	What word comes to mind when you hear 'microbe'?	"Small"	120	63.83	Medium
2.	How often should a person use hand sanitizer?	"Sometimes"	92	48.94	Low
3.	Do you consume probiotics?	"Yes, but rarely"	103	54.79	Low
4.	Which statement about microbes is correct?	"Too small to be seen with the naked eye"	173	92.02	Very High
5.	For human health, microorganisms are:	"Mostly beneficial" and "Half beneficial, half harmful" (tied)	98	52.13 each	Low
6.	How many times per day do you use hand sanitizer?	"Twice"	59	31.38	Low
7.	Which statement do you most agree with?	"Hand sanitizer is a convenient alternative for handwashing"	111	59.04	Medium

Note. Categorization criteria adapted from Mustofa et al. (2021).

The perception profile of students was predominantly moderate to low, with the exception of Item 4, which assessed basic definitional knowledge of microorganisms (92.02%, Very High). This high rate of correct response reflects students' adequate retention of factual, definitional content likely covered in formal biology instruction. However, the overall pattern of perception reveals a critical disconnect between factual knowledge and integrated conceptual understanding. For example, most students associate the word “microbe” with the term “small” (63.83%; moderate category). These findings indicate that students’ understanding of microorganisms is still dominated by simple physical characteristics, rather than by an understanding of the functions, diversity, or ecological roles of microorganisms. Thus, students tend to possess basic factual knowledge but have not yet developed a deeper conceptual understanding of the microbial world.

In line with the research by Azevedo et al. (2024) and Lane et al. (2025), many students have limited and often negative perceptions of microbes, associating them primarily with harm rather than their beneficial roles. For example, only 25% of the children surveyed were aware of the positive contributions of bacteria, and misconceptions about antibiotics and the functions of microbes are very common. Furthermore, Simon et al. (2017) state that misconceptions about viruses and bacteria, such as defining viruses as cells or believing that antibiotics can treat viral infections, are common among students across various educational levels. Therefore, to address this challenge, integrating microbiology topics such as antibiotic resistance into broader social and scientific discussions helps students understand the complexity and relevance of microbiological issues (Sagmeister et al., 2021).

The tied proportions for Item 5 with equal percentages selecting 'mostly beneficial' and 'approximately half beneficial, half harmful' (52.13% each) indicate conceptual ambivalence regarding the overall balance of microbial roles. This ambivalence is theoretically interpretable within the framework of Dual Process Theory (Kahneman, 2011): students' System 1 (fast, intuitive) processing may favor negative stereotypes associated with disease and contamination, while System 2 (deliberate, analytical) engagement with instructional content produces awareness of beneficial microbial roles. The coexistence of these two modes of processing, without adequate integration, produces the kind of perceptual inconsistency observed here.

The Low perception scores for hand sanitizer frequency (31.38%) and probiotic consumption (54.79%) further illustrate the gap between awareness and practice. Students possessed basic hygiene knowledge but had not internalized it into consistent behavioral habits, a pattern consistent with research showing that hygienic awareness among adolescents is often unsupported by behavioral reinforcement and environmental affordances (Dardas et al., 2020; Gund et al., 2022; Guzek et al., 2020). These findings collectively suggest that biology education must go beyond content transmission to

actively engage students in critically examining their own perceptions and biases toward microorganisms.

Attitudes toward Microorganisms

Students' attitudes toward microorganisms were assessed using six Likert-scale items. As presented in Table 6, mean scores ranged from 2.30 to 4.00, yielding an overall mean of 3.48 (Very High). This profile indicates that students hold generally positive attitudinal orientations, though with notable internal variation that reveals important nuances.

Table 6.
Students' Attitudes Toward Microorganisms (n = 188)

No.	Statement	Mean	Category
1.	I do not like touching food that contains bacteria.	3.90	Very High
2.	I would discard the moldy part of bread and eat the part that is not moldy.	2.80	High
3.	Foods containing living microorganisms should be prohibited because they are harmful.	2.30	Moderate
4.	Individuals not vaccinated against infectious diseases pose a threat to themselves.	4.00	Very High
5.	It is unwise to spend time with people who have respiratory diseases.	3.25	Very High
6.	Knowledge about microorganisms is important and useful.	4.00	Very High
	Overall Mean	3.48	Very High

Note. Categorization criteria adapted from Mustofa and Sueb (2023).

The highest attitude scores were recorded for Items 4 and 6 (M = 4.00, Very High each), reflecting students' recognition of the importance of vaccination for disease prevention and the perceived value of microbiological knowledge. These findings align with Lubej & Kirbiš (2025), who reported that health literacy is positively associated with pro-vaccination attitudes and disease-prevention readiness. Health literacy enhances health-protective behaviors, such as hand hygiene and adherence to preventive measures during pandemics (e.g., COVID-19. This is achieved by improving knowledge and reducing perceived barriers to action (Mustofa et al., 2025; Shan et al., 2023; Zhang et al., 2022). Item 1 (M = 3.90, Very High), which captured aversion to foods containing bacteria, also scored highly, reflecting a cautious attitudinal orientation consistent with a predominantly pathogenic framing of microorganisms.

Item 3 yielded the lowest attitude score (M = 2.30, Moderate), indicating that many students favored prohibiting foods containing living microorganisms. This finding is scientifically concerning, as it reflects a failure to distinguish between pathogenic and non-pathogenic or beneficial microorganisms, including probiotic species. This attitudinal pattern is consistent with Timmis et al., (2019) argument that low microbiology literacy manifests not only in knowledge deficits but in attitudinal dispositions that can lead to counterproductive behaviors such as avoiding fermented foods, rejecting probiotics, or supporting unnecessary disinfection measures. Item 2 (M = 2.80, High) revealed that many students would consume bread after removing visibly moldy sections, suggesting a misconception regarding the localized nature of fungal contamination. From a scientific standpoint, mycotoxins and fungal hyphae can penetrate deep into food substrates, beyond the visible mold boundary. This partial knowledge understanding that contamination exists, yet underestimating its extent exemplifies the fragmented scientific thinking and represents a direct food safety risk (Righi et al., 2024). Fragmentation can lead to a disjointed understanding and hinder the ability to connect concepts, which is critical for addressing complex issues such as contamination (Lutfia & Kholid, 2026; Nuriyah & Kholid, 2024).

These findings are interpretable within Ajzen's (1991) Theory of Planned Behavior, which posits that attitudes arise from behavioral beliefs, normative pressures, and perceived control. Students' cautious attitudes toward bacterial foods (Item 1) and their partial acceptance of probiotics (Items 3 and 5 from perception data) may reflect prevailing social norms that cast microbes primarily as threats, rather than cognitive conclusions derived from scientific reasoning. These findings underscore the need for affective and normative dimensions of microbiology education not only to transmit conceptual content but also to actively reshape the social and emotional frameworks through which students interpret microbial phenomena.

Behaviors toward Microorganisms

Students' microorganism-related behaviors were assessed across six multiple-choice items encompassing hand hygiene, food safety, contamination identification, surface disinfection, and expiration date checking. As shown in Table 7, behavioral scores ranged from the Low to Very High categories, revealing significant variation across domains of practice.

Table 7.
Students' Behavioral Practices Toward Microorganisms (n = 188)

No.	Question	Most Selected Response	N	%	Category
1.	Do you know how to wash hands properly to prevent microbial spread?	"Yes, I know and practice it regularly."	122	64.89	Medium
2.	If you find food contaminated with bacteria, what would you do?	"Dispose of it safely and wash my hands."	172	91.49	Very High
3.	Do you know how to store food properly to prevent microbial growth?	"Yes, I know and practice it regularly."	88	46.81	Low
4.	Are you able to identify signs of microbial contamination in food?	"Yes, I can identify them well."	103	54.79	Low
5.	How do you clean frequently touched surfaces?	"Using disinfectants regularly."	91	48.40	Low
6.	Do you check expiration dates on food and beverages?	"Always."	137	72.87	High

Note. Categorization criteria adapted from Mustofa et al. (2021).

The highest behavioral score was observed for Item 2 (91.49%, Very High), in which the overwhelming majority of students reported that they would safely dispose of bacterially contaminated food and wash their hands. This finding indicates strong risk-avoidance behavior in high-salience food safety scenarios. Similarly, Item 6 (72.87%, High) showed that most students habitually check food expiration dates, suggesting that consumer-oriented food safety practices have been effectively socialized, possibly through family education or public health campaigns. In contrast, Items 3, 4, and 5 all fell within the Low category. Only 46.81% of students reported consistent knowledge and practice of proper food storage to prevent microbial growth; 54.79% reported being able to identify signs of contamination in food; and 48.40% reported using disinfectants regularly for surface cleaning. These findings reveal a clear behavioral paradox: students demonstrate strong reactive behaviors in response to perceived contamination (Item 2) but weaker proactive, preventive behaviors (Items 3–5). This pattern is consistent with Cognitive Dissonance Theory (Festinger, 1957), which predicts that individuals tend to minimize psychological discomfort by selectively engaging in behaviors that align with salient beliefs while ignoring those that require sustained effort or challenge habitual practices.

These behavioral inconsistencies can also be interpreted through the Health Belief Model (Rosenstock, 1974), which holds that preventive health behaviors are predicted by perceived susceptibility, perceived severity, perceived benefits, perceived barriers, and cues to action. Students' strong disposal and handwashing behaviors likely reflect high perceived susceptibility and severity of contamination, whereas lower scores in food storage and surface disinfection may indicate insufficient perceived susceptibility in non-emergency contexts. The practical implications for biology education are clear: instruction must not only convey factual content but also target the perceptual and motivational barriers that prevent consistent translation of knowledge into everyday preventive practice. Based on these findings, several concrete recommendations can be advanced, particularly in relation to education policy. First, the national biology curriculum (Kurikulum Merdeka) should explicitly position microbiology literacy as a measurable learning outcome that integrates the cognitive, affective, and behavioral domains, rather than treating microorganisms primarily as agents of disease. Second, education authorities at the district level (such as the Tuban Regency Education Office) should mandate context-based and inquiry-driven microbiology modules that connect classroom concepts to students' everyday practices in food storage, fermentation, and hygiene. Third, sustained teacher professional development programs are needed to equip educators with strategies to diagnose and address microbial misconceptions and to translate knowledge into preventive behavior. Fourth, schools in non-urban areas should be prioritized for laboratory facilities and health-promotion partnerships to reduce the resource gap that constrains hands-on microbiology learning. Finally, microbiology literacy should be embedded within broader national health- and science-literacy policy frameworks, with periodic monitoring of students' knowledge, attitudes, perceptions, and behaviors to evaluate the impact of

curricular reforms.

CONCLUSION

This study demonstrates that senior high school students in Tuban Regency possess a functional but fragmented profile of microbiological knowledge, attitudes, perceptions, and behaviors. While knowledge scores were generally high, conceptual understanding remained incomplete, as evidenced by persistent ambiguity about the predominantly non-pathogenic nature of bacteria. Perceptions were predominantly moderate to low, reflecting an over-reliance on pathogenic framing that is not fully resolved by existing biology instruction. Attitudes were very high overall, yet critical inconsistencies, particularly in food safety decision-making and the rejection of foods containing beneficial microorganisms, indicate that attitudinal positivity does not guarantee scientifically sound reasoning. Behavioral practices showed a paradox between strong reactive hygiene responses and weaker proactive preventive habits, particularly in food storage, contamination identification, and surface disinfection. These findings collectively confirm the presence of a knowledge-attitude-behavior gap that cannot be addressed through content transmission alone. The implications for biology education are substantial: curriculum designers should develop instructional frameworks that explicitly integrate conceptual knowledge, attitudinal development, and behavioral skill-building within authentic contexts; teachers should employ inquiry-based and problem-based strategies that challenge negative microbial stereotypes and promote balanced, evidence-based reasoning; and educational policy should prioritize microbiological literacy as a component of broader health and scientific literacy frameworks, particularly for students in non-urban settings with limited access to health promotion resources. Future research should examine longitudinal changes in KAP dimensions following targeted instructional interventions, with attention to socioeconomic and contextual factors that moderate behavioral outcomes.

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