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Biology Teachers' Readiness to Implement STEM Three-Dimensional Learning on Water Quality: A Pre-Training Needs Assessment Relevant to SDGS 6

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ABSTRACT

This study reports a pre-training needs assessment of the initial readiness of senior high school biology teachers in Klaten Regency to implement STEM three-dimensional learning (STEM-3DL) on the topic of water quality, conducted as part of the international community service program, Community Development Program EQUITY THE Impact Rankings 2025 Grant of Universitas Sebelas Maret (UNS) in partnership with Chulalongkorn University, Thailand. This study uses a descriptive survey method with a Likert scale questionnaire instrument (1–4) covering seven dimensions: (1) understanding and attitudes towards STEM, (2) Project-Based Learning, (3) science and engineering practices, (4) Scientific Explanation through Claim-Evidence-Reasoning (CER), (5) Scientific Modeling, (6) Water Quality and SDGs 6, and (7) STEM three-dimensional learning. Twenty-four biology teachers from various high schools in Klaten Regency took part in the program; the 21 who returned complete questionnaires, representing 19 schools, were included in the analysis. The overall mean score was 2.88 (scale 1–4), which falls in the 'good' category and indicates a generally favorable but uneven readiness profile. A total of 90.5% of respondents had never participated in STEM training. The dimensions with the highest mean scores were STEM three-dimensional learning (3.17) and Scientific Modeling (3.05), while the lowest were Project-Based Learning (2.68) and CER (2.72). Across all seven dimensions, items expressing belief in the value of STEM scored higher than items measuring teachers' perceived ability to enact it. The main contribution of this needs assessment is a dimension-level readiness profile that locates the gap in enactment rather than conviction and can be used to target subsequent teacher professional development; future research should test whether this belief–enactment pattern narrows after training and whether it holds for biology teachers in other Indonesian regions.

Keywords: STEM-3DL; senior high school biology teachers; CER (Claim-Evidence-Reasoning); SDGs 6; international community service; needs assessment

Introduction

Water is a vital resource for life and for sustainable development. The sixth Sustainable Development Goal, Clean Water and Sanitation, stresses the importance of universal access to safe water and adequate sanitation for the world population by 2030 (United Nations, 2015). In the local context, Klaten is a region rich in water sources, including natural springs and ponds that have become leading tourist attractions. Industrial activity, the growth of residential areas, and the economic dynamics of local communities have nonetheless placed pressure on the quality of these water sources, and indications of pollution have begun to emerge. Recent studies bear this out: coliform counts in the Tirtomulyono and Tirtomulyani springs of Kebonarum District, Klaten, exceeded the national standard for safe water (Khasanah & Purnama, 2023), while batik small-industry effluent has raised the pollution load carried by local rivers and water sources in the regency (Handayani et al., 2021).

Biology education plays a strategic role in cultivating scientific awareness and competence regarding environmental issues, including water quality. Biology teachers are particularly well placed to address it, because water quality is fundamentally a matter of living indicators, ecosystems, and human health that connects directly to the science their students already study (Purwianingsih et al., 2025). One relevant instructional approach is STEM, which integrates several disciplines contextually and around real phenomena (Kelley & Knowles, 2016; Bybee, 2013). Framing water quality through STEM allows teachers to treat a local water source as an engineering and data problem as much as a biological one, which is the connection this study set out to assess. Although STEM implementation in Indonesia has grown since 2014 (Farwati et al., 2021), its application in classroom learning remains very limited (Permanasari et al., 2021). Nugroho et al. (2019) found that while science teachers generally understand STEM at a conceptual level, few have genuinely implemented it in their classrooms.

Three-dimensional learning is a science learning framework developed by the National Research Council and forms the basis of the Next Generation Science Standards in the United States. The framework integrates disciplinary core ideas, science and engineering practices, and crosscutting concepts (NRC, 2012; NGSS Lead States, 2013). Integrating STEM with three-dimensional learning offers an approach that not only develops content understanding but also trains students to think and work in the way that scientists actually do (Krajcik & Shin, 2014). In this study, the two are integrated by treating STEM as the disciplinary content and real-world context, and the three dimensions—disciplinary core ideas, science and engineering practices, and crosscutting concepts—as the means through which that content is learned, so that a water-quality problem becomes the vehicle for practices such as modelling and argumentation.

One scientific practice emphasized in this integration is constructing a scientific explanation through the claim, evidence, and reasoning (CER) framework, which trains students to ground explanations in valid evidence and reasoning (McNeill & Krajcik, 2012). CER is given particular weight in this study because argumentation from evidence most directly turns water-quality data into scientific reasoning, and it is also among the practices Indonesian science teachers report as the hardest to teach. The subsequent training program also proposes the use of SimRiver, a web-based simulation application developed at Tokyo

Gakugei University that simulates the relationship between human activity, river water quality, and diatom communities as bioindicators of water quality (Mayama et al., 2011); SimRiver is a medium proposed for that training rather than an object evaluated in the present needs assessment.

In support of the fourth, sixth, and seventeenth Sustainable Development Goals, the RG STEAM Education team of FKIP UNS, together with Chulalongkorn University and the Klaten Regency biology teacher working group, carried out an international community service program funded by the Community Development Program EQUITY THE Impact Rankings 2025 Grant of Universitas Sebelas Maret. Before delivering the activities, a needs assessment of participants' knowledge and readiness was essential to design a well-targeted program (Ramli et al., 2023). This article reports on the needs assessment. Although Indonesian studies have documented teachers' general familiarity with STEM (Nugroho et al., 2019; Permanasari et al., 2021), few have profiled readiness at the level of the specific pedagogical practices required for a concrete local issue such as water quality, and fewer still have done so as a pre-training diagnostic; this needs assessment addresses that gap. It addresses three questions: the initial readiness profile of senior high school biology teachers in Klaten with respect to STEM three-dimensional learning, which dimensions require the most significant strengthening, and the implications for the design of the training program

Methods

This This study used a quantitative descriptive approach with a survey method, appropriate for describing the characteristics of a population at a single point in time (Fraenkel et al., 2012), which suits the aim of profiling rather than manipulating teachers' readiness before any training. Data were collected through a pre-training questionnaire administered from February to March 2025 in Klaten Regency, Central Java, before the community service program was delivered.

The target population was senior high school biology teachers in the Klaten Regency biology teachers' working group (MGMP), the professional forum invited to take part in the program; all active members were invited through the working group. Participants were purposively selected based on two criteria: they were actively teaching biology at senior high school. They were willing to attend the full series of program activities, so the assessment would reflect teachers genuinely positioned to implement the approach. Twenty-four teachers enrolled as program participants; of these, 21 teachers representing 19 schools returned a complete questionnaire (an 87,5 per cent response rate) and constitute the analytic sample, while the three who did not complete the questionnaire were excluded from analysis. Because the sample is purposive and drawn from a single regency, the findings describe this group and comparable working groups rather than all Indonesian biology teachers, a limitation revisited below.

The instrument was a questionnaire developed by the research team for this study, using a four-point Likert scale in which 1 indicates strongly disagree or no understanding and 4 indicates strongly agree or very good understanding. Because the dimensions span attitudes, conceptual understanding, and perceived pedagogical competence, each item was phrased so that this common anchor applied to the specific construct it measured. It consisted of forty statement items grouped into seven dimensions: STEM understanding and attitudes (items 1 to 6), project-based learning (items 7 to 12), STEM science and engineering practices (items 13 to 21), scientific explanation through claim, evidence, and reasoning (items 22 to 26), scientific modelling (items 27 to 29), water quality and the sixth Sustainable Development Goal (items 30 to 36), and STEM three-dimensional learning (items 37 to 40). The items were derived from established frameworks: STEM integration (Kelley & Knowles, 2016; Bybee, 2013), three-dimensional learning and the science and engineering practices (NRC, 2012; NGSS Lead States, 2013), the CER framework (McNeill & Krajcik, 2012), and the water-quality and SDG 6 content of the program. Each dimension therefore operationalizes readiness for one component that teachers would later be asked to enact. Content validity was established by grounding the items in these frameworks and confirmed through review by 2 expert validators in science and biology education. The instrument's internal-consistency reliability was acceptable, with an overall Cronbach's alpha of 0.82 across the forty items. Ten items are negatively worded and describe perceived obstacles or weaknesses, namely items 2, 4, 6, 8, 9, 10, 12, 13, 16, and 24. These items were deliberately scored in their original direction rather than reverse-scored: a low score on a barrier item is itself the diagnostic signal that the obstacle is strongly felt, and reverse-scoring would fold these barrier perceptions into the same composite as the capability items and mask the very difficulties a needs assessment is intended to surface. Consequently, the dimension and overall means are read descriptively as a profile; negatively worded (barrier) items are interpreted separately from positively worded (belief and capability) items throughout the Results, and the trade-off of this choice is noted in the Limitations.

The data were analyzed descriptively using the mean and standard deviation together with frequency and percentage distributions. Each dimension score was computed as the mean of its constituent items and the overall score as the mean across all forty items, with negatively worded items entered in their original direction as described above. Scores were categorized as low for means from 1.00 to 1.75, fair for means from 1.76 to 2.50, good for means from 2.51 to 3.25, and very good for means from 3.26 to 4.00. Data visualization was carried out in Python using the matplotlib and pandas libraries.

Results and Discussion

Demographic Profile of the Participants

Twenty-one of the twenty-four biology teachers from nineteen senior high schools in Klaten Regency completed the questionnaire. Their demographic characteristics are presented in Table 1 and Figure 1.

Table 1. Demographic characteristics of the participants (n = 21)

Characteristic	Category	n	%
Gender	Female	17	81.0
	Male	4	19.0
Teaching experience	Less than 5 years	7	33.3
	5 to 10 years	5	23.8
	11 to 20 years	3	14.3
	More than 20 years	6	28.6
Grade level taught	Grade X	8	38.1
	Grade XI	4	19.0
	Grade XII	9	42.9
STEM training experience	Ever attended	2	9.5
	Never attended	19	90.5

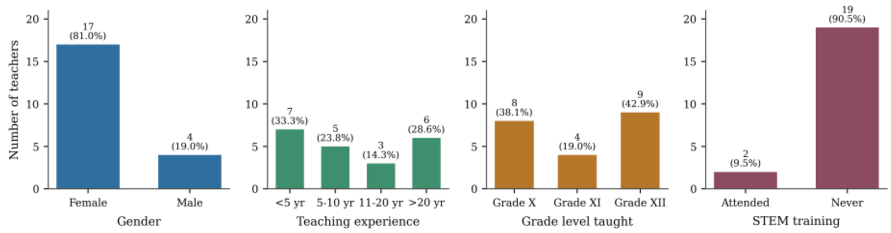

Figure 1. Demographic profile of the participating teachers (n = 21)

Most participants were female teachers, and teaching experience was fairly evenly distributed across the career span. A key descriptive finding is that 90.5 percent of respondents—19 of the 21 teachers who completed the questionnaire—had never attended any STEM training. This result aligns with Nugroho et al. (2019), whose study of 117 Indonesian science teachers found that although most teachers understand STEM conceptually, few have genuinely implemented it in their teaching. Farwati et al. (2021) likewise confirm that access to systematic STEM training for senior high school teachers remains very limited.

Readiness Across the Seven Dimensions

The mean scores and standard deviations for each dimension are presented in Table 2 and Figure 2. The overall mean of 2.88 falls in the 'good' category on the scale used here. It indicates a generally favorable but uneven readiness profile, with the spread between the highest and lowest dimensions close to half a scale point.

Table 2. Mean scores per questionnaire dimension (n = 21, scale of 1 to 4)

Dimension	Items	Mean	SD	Category
STEM understanding and attitudes	6	2.75	0.73	Good
Project-based learning	6	2.68	0.75	Good
STEM science and engineering practices	9	2.83	0.77	Good
Scientific explanation (CER)	5	2.72	0.72	Good
Scientific modeling	3	3.05	0.65	Good
Water quality and SDGs 6	7	2.95	0.64	Good
STEM three-dimensional learning	4	3.17	0.63	Good
Overall	40	2.88	0.70	Good

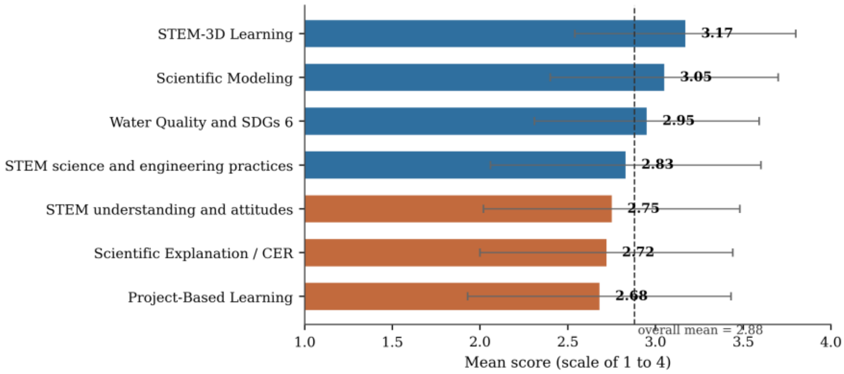

Figure 2. Mean score per questionnaire dimension with standard deviation (n = 21); the dashed line marks the overall mean of 2.88

Readiness for STEM and Project-Based Learning

That 90.5 percent of the responding teachers had never attended STEM training is among the most consequential findings of this needs assessment. In a scoping review of 154 STEM articles published in Indonesia between 2015 and 2020, Farwati et al. (2021) confirm that STEM training programs still reach higher education far more than senior high school teachers. Permanasari et al. (2021) recommend reorienting science teacher training through lesson analysis using a range of STEM best practices systematically and continuously.

Project-based learning obtained the lowest dimension mean of 2.68. The positively worded items show that teachers acknowledge its benefits for student engagement (item 7, mean 3.67) and learning motivation (item 11, mean 3.48). The negatively worded items on implementation obstacles, however, received very low scores (item 10, mean 2.05; item 12, mean 2.05), which indicates a real perception of practical difficulty. This result is consistent with Muchtar et al. (2024), who found that project-based learning is the most frequently used method in STEM in Indonesia, while teachers still face significant obstacles in time and classroom management.

Readiness in Scientific Explanation

The scientific explanation dimension obtained a mean of 2.72, with a marked disparity between items. Teachers have a sound conceptual understanding of what a scientific explanation is (item 22, mean 3.29), yet operational skills such as constructing an assessment rubric (item 25, mean 2.24) and determining student ability (item 26, mean 2.29) remain low. This pattern reflects a gap between teachers' conceptual understanding and their perceived capacity to implement—perceived because the data are self-reported and do not observe actual classroom practice—which McNeill and Krajcik (2012) identify as the principal challenge in encouraging teachers to teach evidence-based argumentation. Teachers need training not only to understand the framework, but also to design learning activities, develop guiding questions, and evaluate student argumentation through valid rubrics.

Item 24, which is negatively worded and states that teaching argumentation is sufficient by explaining the concept and asking students to read, obtained a score of 2.81. The moderate score on this single self-reported item suggests that some teachers may still lean toward a knowledge-transmission approach. However, this reading rests on one item and would need corroboration from classroom observation. Krajcik (2015) stresses that genuine three-dimensional learning requires students to engage actively in sense-making of phenomena rather than simply receiving verbal explanations from the teacher.

Readiness for Water Quality and SDGs 6

The water quality dimension obtained a mean of 2.95, and the same pattern recurs. Items measuring belief in the importance of water quality obtained high scores, namely item 36 on the importance of teaching the material at senior high school (mean 3.71) and item 34 on building student awareness (mean 3.48). Items measuring actual pedagogical capability remain relatively low, including the ability to teach and conduct practical work on water quality (item 30, mean 2.48) and the understanding of water bioconservation in relation to the sixth Sustainable Development Goal (item 32, mean 2.52).

This gap between awareness and perceived pedagogical capacity provides a strong rationale for proposing SimRiver as a medium in the subsequent training program; its effectiveness is not evaluated in the present study and cannot be inferred from these data. SimRiver is a web-based river ecosystem simulation developed at Tokyo Gakugei University that allows users to simulate relationships among land use, population density, waste management, and water quality based on diatom communities as bioindicators (Mayama et al., 2011). The Diatom Project, the umbrella program for SimRiver, is available in twenty-five languages and is used in schools in Japan, India, the United States, and Thailand (Mayama et al., 2021), which makes it an appropriate medium for an international learning context.

Readiness for STEM Three-Dimensional Learning

The STEM three-dimensional learning dimension obtained the highest mean of 3.17. Teachers showed strong appreciation of its potential to improve student scientific literacy (item 38, mean 3.38), of the value of argumentation-oriented STEM (item 39, mean 3.38), and of the belief that applying the three dimensions can improve the achievement of Indonesian students in international assessments (item 40, mean 3.38). Operational understanding of how to implement the approach in the classroom (item 37) remains lower, at a mean of 2.52.

This is understandable, given that the National Research Council (2012) framework and the Next Generation Science Standards are relatively recent introductions in Indonesia. The three dimensions demand a shift in the learning paradigm, away from teacher-centered transmission and towards student-centered sense-making of phenomena (NGSS Lead States, 2013; Krajcik, 2015). This shift is visible in the present data, where teachers endorsed the value of the three dimensions (items 38 to 40, each mean 3.38) far more strongly than their own grasp of how to enact them in the classroom (item 37, mean 2.52). Such a shift requires professional development that is intensive, sustained, and grounded in real classroom practice, as reported in recent Indonesian STEM training for senior high school teachers (Purwianingsih et al., 2025).

Item-Level Findings

Table 3 presents the descriptive statistics for all forty items. Read together with the dimension means, it shows that the belief-capability gap is not confined to one dimension but recurs throughout the instrument. The five highest-scoring items are all statements of value or principle, while the five lowest are all statements about what the teacher can actually do. Read across the whole instrument, this is a consistent perceived belief–enactment pattern: teachers are convinced of the value of these approaches yet rate their own enactment lower, which directs professional development toward supervised practice in lesson design, rubric construction, and assessment rather than further awareness-raising.

Table 3. Descriptive statistics for all forty questionnaire items (n = 21)

Item	Statement	Mean	SD	Min/Max
1	Understanding of STEM-based biology learning	2.57	0.60	2/4
2	Implementing STEM requires too much preparation time a	2.67	0.91	1/4
3	Able to manage the classroom efficiently with STEM	2.81	0.60	2/4
4	STEM is not suitable for all students a	1.95	0.80	1/4
5	STEM uses the way scientists work to solve real problems	3.76	0.54	2/4
6	STEM resources are not available at school a	2.76	0.83	1/4
7	Project-based learning increases student engagement	3.67	0.48	3/4
8	Project-based learning requires too much time a	2.62	0.86	1/4
9	Difficulty in managing the classroom with project-based learning a	2.19	0.75	1/4
10	Project-based learning is not suitable for all topics a	2.05	1.02	1/4
11	Project-based learning increases student learning motivation	3.48	0.51	3/4
12	Students are not serious in completing projects a	2.05	0.86	1/4
13	Difficulty in implementing STEM-integrated biology learning a	2.33	0.66	1/4
14	Physics, chemistry, and earth science should be integrated into biology	3.10	0.94	1/4
15	Technology and mathematics need to be integrated into biology	3.52	0.51	3/4
16	Science phenomena can be understood from a single discipline alone a	2.33	1.11	1/4
17	Understanding cross-disciplinary science concepts	2.81	0.81	1/4
18	Understanding the scientist and engineer skills taught to students	3.05	0.74	2/4
19	Understanding how to teach students to construct scientific explanations	3.00	0.55	2/4

Item	Statement	Mean	SD	Min/Max
20	Understanding scientific argumentation through claim, evidence, and reasoning	2.57	0.68	1/4
21	Understanding the link between scientific modelling and argumentation	2.76	0.62	1/4
22	Scientific explanation means explaining phenomena with evidence and reasoning	3.29	0.56	2/4
23	The framework consists of claim, evidence, and reasoning	3.00	0.55	2/4
24	Teaching argumentation is enough by explaining and asking students to read a	2.81	0.98	1/4
25	Able to construct a rubric to measure student argumentation	2.24	0.77	1/4
26	Understanding how to determine student argumentation ability	2.29	0.72	1/4
27	Scientific modelling is a conceptual representation of science phenomena	2.86	0.73	2/4
28	Scientific modelling covers physical, mathematical, and conceptual models	3.10	0.62	2/4
29	Scientific modelling is an illustrative tool, not merely an explanation	3.19	0.60	2/4
30	Understanding how to teach and conduct practical work on water quality	2.48	0.60	2/4
31	Understanding water quality concepts to be taught to students	2.57	0.68	2/4
32	Understanding the principles of water bioconservation within SDGs 6	2.52	0.75	1/4
33	Skilled in using water quality learning media	2.48	0.60	2/4
34	Water quality material builds student awareness of the importance of water	3.48	0.60	2/4
35	Simulation and game media help students understand water pollution	3.43	0.51	3/4
36	Water quality material is important to teach at senior high school	3.71	0.46	3/4
37	Understanding biology learning based on STEM, three dimensions, and argumentation	2.52	0.68	1/4
38	Three-dimensional learning can improve student scientific literacy	3.38	0.59	2/4
39	Argumentation-oriented STEM trains evidence-based reasoning	3.38	0.67	2/4
40	The three dimensions can improve national achievement in science assessments	3.38	0.59	2/4

[a] negatively worded item; the minimum and maximum values reflect the actual range of responses

Limitations

Three limitations qualify these findings. First, the sample is small and purposive and comes from a single regency, so the profile describes this working group rather than Indonesian biology teachers in general. Second, the data are self-reported measures of perceived readiness and do not observe actual classroom practice, so the belief–enactment gap reported here is perceived. Third, the ten negatively worded items were scored in their original direction. However, this is deliberate and suits a barrier-focused diagnostic; a reverse-scored composite could change the dimension means and their ranking, so the composite scores should be read descriptively rather than as a validated readiness scale.

Conclusion

Senior high school biology teachers in Klaten Regency show a readiness profile that falls in the 'good' category (overall mean 2.88 on a four-point scale) but is uneven, and 90.5 percent of the responding teachers had never attended any STEM training. The distinctive finding of this needs assessment is that readiness is limited less by conviction than by perceived enactment: across all seven dimensions, items expressing belief in the value of STEM, project-based learning, argumentation, and water quality education scored consistently high, while items measuring the perceived ability to design lessons, build rubrics, and run practical work scored consistently low, with project-based learning (2.68) and scientific explanation (2.72) weakest overall. Its contribution is to locate that gap at the level of specific practices, so that subsequent professional development can be targeted rather than generic.

The training program was therefore designed around hands-on practice with the claim, evidence, and reasoning framework in a water quality context, the development of ready-to-implement lesson plans, training in using SimRiver as a diatom simulation medium, and the construction of applicable assessment rubrics. These design choices follow from the assessment; the present study reports the pre-training needs assessment only and does not evaluate the effectiveness of the training or its proposed components. Because the present data are descriptive and cover only the pre-training stage, a follow-up study using post-program data is needed to establish whether this enactment gap narrows, and further research could usefully test whether the same belief and capability pattern holds for science teachers in other Indonesian regions.

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Generative AI Disclosure

The use of artificial intelligence in this manuscript is limited to language translation and editing to improve readability, without affecting the scientific substance, data analysis, or research interpretation.

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