

Development of a STEM-Based E-Module for Water Quality Management in Brackish and Marine Fisheries Agribusiness Learning

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Received: June 21, 2026

Revised: September 27, 2026

Accepted: October 2, 2026

Published: October 31, 2026

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DOI: [10.29303/jppipa.v12i10.15788](https://doi.org/10.29303/jppipa.v12i10.15788)

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Abstract: Water Quality Management is an essential competency in Brackish and Marine Fisheries Agribusiness because it requires students to integrate scientific knowledge, technology, quantitative analysis, and problem-solving skills in authentic aquaculture contexts. However, learning activities are still predominantly supported by conventional materials, while the use of digital learning resources remains limited. This study aimed to develop a STEM-based e-module for Water Quality Management and determine its validity, practicality, and effectiveness as a learning resource for vocational high school students. This study employed a Research and Development (R&D) approach using the ADDIE model, consisting of Analysis, Design, Development, Implementation, and Evaluation. The participants were 15 eleventh-grade students of the Brackish and Marine Fisheries Agribusiness Program and one subject teacher at SMK Negeri 1 Seri Kuala Lobam. Data were collected through expert validation sheets, teacher and student response questionnaires, and pretest-posttest assessments. The results showed that the e-module was highly valid and highly practical, with validation and practicality scores of 93.75% and 98.6%, respectively. Learning outcomes improved from a mean pretest score of 73.0 to 90.0, with an N-Gain of 0.61, categorized as moderate. The t-test indicated a significant difference between pretest and posttest scores ($p < 0.05$). These findings indicate that the STEM-based e-module is a valid, practical, and effective digital learning resource for Water Quality Management in vocational fisheries education.

Keywords: E-Module; Learning Media; STEM; Vocational Education; Water Quality Management

Introduction

The Brackish and Marine Fisheries Agribusiness sector requires vocational learning that enables students to integrate scientific knowledge, technological skills, and problem-solving abilities with authentic aquaculture practices (Briyanda et al., 2023; Lessy et al., 2026; Noor et al., 2025). One of the essential competencies in this field is Water Quality Management because water conditions directly influence fish or shrimp growth, health, productivity, and the sustainability of aquaculture systems (Lokollo et al.,

2025; Pratiwi et al., 2024; Riyadi & Liubana, 2025). Students are therefore expected not only to understand water-quality concepts but also to investigate environmental conditions, interpret measurement results, and determine appropriate management strategies based on relevant evidence (Adianto et al., 2024; Lindholm-Lehto, 2023; Nagothu et al., 2025). This characteristic makes Water Quality Management an important area for vocational learning that connects scientific concepts with technological applications and practical decision-making in aquaculture.

How to Cite:

Yumitra, H., Rayendra, R., Darmansyah, D., & Yeni J, F. (2026). Development of a STEM-Based E-Module for Water Quality Management in Brackish and Marine Fisheries Agribusiness Learning. *Jurnal Penelitian Pendidikan IPA*, 12(10), 39-46. <https://doi.org/10.29303/jppipa.v12i10.15788>

Water Quality Management encompasses physical, chemical, and biological parameters, including temperature, pH, dissolved oxygen, salinity, and ammonia (Janna et al., 2022). Understanding these parameters requires students to recognize their functions, interpret relationships among them, identify factors that cause changes in water quality, and determine appropriate responses to maintain suitable aquaculture conditions (Iskandar et al., 2025). Such competencies require learning experiences that extend beyond conceptual explanations by providing opportunities to examine contextual problems, interpret measurement data, and connect scientific principles with technical solutions (Pixyoriza et al., 2022). Learning resources for this subject therefore need to facilitate the integration of conceptual knowledge, technological applications, quantitative analysis, and problem solving within relevant aquaculture contexts.

The need for such learning resources was identified through preliminary observations at SMK Negeri 1 Seri Kuala Lobam. The observation showed that 95% of students owned smartphones, indicating sufficient access to digital devices that could potentially support technology-enhanced learning. However, the availability of these devices had not been accompanied by optimal utilization of digital technology for learning. Approximately 75% of students experienced difficulties in understanding Water Quality Management concepts, while classroom activities remained predominantly dependent on textbooks, PowerPoint presentations, and printed worksheets. These learning resources provided limited opportunities for students to visualize changes in water-quality conditions, investigate relationships among parameters, interpret monitoring results, and formulate solutions to contextual aquaculture problems. This condition indicates a gap between students' access to digital technology and the availability of learning resources that effectively utilize digital technology to support contextual, student-centered, and problem-oriented vocational learning.

An electronic module (e-module) can provide a structured digital learning environment that integrates learning materials, multimedia, activities, and assessment within a single learning resource (Lestari et al., 2025). However, the conversion of conventional materials into electronic format does not automatically ensure the development of higher-order thinking or practical problem-solving competencies (Sari et al., 2025). The effectiveness of an e-module depends on how its content and learning activities are organized to engage students in meaningful cognitive and practical processes (Lidiana & Sukestiyarno, 2023). For Water Quality Management, an appropriate e-module should therefore provide students with opportunities to investigate authentic problems, use relevant

technologies, analyze data, apply interdisciplinary knowledge, and communicate evidence-based solutions.

The Science, Technology, Engineering, and Mathematics (STEM) approach provides a relevant pedagogical framework for addressing these requirements (Briyanda et al., 2023; Deliana & Anwar, 2025; Nilyani et al., 2023; Sawu et al., 2023). Integrated STEM connects scientific inquiry with technological applications, engineering design or solution development, and mathematical reasoning to address authentic problems (Kelley & Knowles, 2016). In Water Quality Management, these dimensions can be integrated naturally. Science enables students to investigate water-quality principles and environmental processes; technology supports the use of monitoring instruments and digital information resources; engineering encourages students to determine or develop technical solutions to water-quality problems; and mathematics enables students to process, interpret, and evaluate quantitative measurement data (Arepalli & Naik, 2024; Mohd Jais et al., 2024; Sundari et al., 2025). Consequently, STEM provides a framework for connecting theoretical knowledge with the practical competencies required in aquaculture.

In this study, the STEM learning activities are organized through the stages of Reflection, Research, Discovery, Application, and Communication. During Reflection, students are introduced to contextual aquaculture problems, such as inappropriate pH, dissolved oxygen, salinity, or ammonia levels, and relate these problems to their prior knowledge and experiences. During Research, students investigate information concerning water-quality parameters, suitable ranges, measurement procedures, and factors contributing to changes in water conditions. During Discovery, students analyze the information and measurement data obtained to identify relationships, determine possible causes of water-quality problems, and formulate alternative solutions. During Application, students apply scientific, technological, engineering, and mathematical knowledge to determine or develop appropriate management strategies, such as aeration, filtration, or other interventions. During Communication, students present their findings, explain the proposed solutions, and provide evidence supporting their decisions. This sequence enables students to move from recognizing a contextual problem to investigating evidence, discovering relationships, applying interdisciplinary knowledge, and communicating solutions. The use of these five stages in STEM-integrated e-modules has also been reported in previous development research, demonstrating their potential to structure problem-solving activities in digital learning resources.

Previous studies have demonstrated the potential of STEM-integrated digital learning resources to support students' higher-order competencies and problem-solving abilities (Lestari et al., 2025). More recent research has also explored STEM-based e-modules in vocational education, including the integration of STEM with multimedia and digital technologies to support students' learning competencies (Febriani & Warty, 2026). Nevertheless, the identified studies have predominantly focused on general science and other disciplinary contexts, while studies applying STEM-based e-modules specifically within vocational fisheries education remain limited. In particular, the identified literature provides limited evidence regarding e-modules that integrate STEM with Water Quality Management competencies and authentic aquaculture problems within the Brackish and Marine Fisheries Agribusiness subject.

This gap is important because Water Quality Management in vocational fisheries education has distinctive characteristics that require students to integrate scientific understanding with practical aquaculture decision-making (Farkan et al., 2025). Students must be able to identify water-quality problems, interpret measurement results, understand their implications for cultivated organisms, and determine appropriate technical responses. Therefore, an effective digital learning resource for this context should not merely provide electronic access to theoretical material but should facilitate an integrated learning process in which students investigate problems, analyze evidence, apply interdisciplinary knowledge, and communicate practical solutions.

The novelty of this study lies in the development of a STEM-based e-module specifically designed for the Water Quality Management element in the Brackish and Marine Fisheries Agribusiness subject at the vocational high school level. The developed e-module integrates water-quality concepts, digital monitoring technologies, engineering-oriented problem solving, quantitative data analysis, and authentic aquaculture situations within a structured STEM learning sequence. In particular, the Reflection, Research, Discovery, Application, and Communication stages are directly contextualized to water-quality problems so that each stage contributes to the development of students' ability to investigate, interpret, solve, and communicate solutions to aquaculture-related problems. This contextual integration distinguishes the developed resource from STEM e-modules developed for general science topics and provides a specific contribution to the development of digital learning resources for vocational fisheries education.

The development of this learning resource is therefore important in responding to the identified

learning difficulties, the limited utilization of students' available digital devices, and the need for vocational learning that connects theoretical knowledge with authentic aquaculture practices. By integrating STEM principles into an e-module specifically designed for Water Quality Management, the learning resource is expected to provide students with more contextual, interactive, and problem-oriented learning experiences while supporting the competencies required in their vocational field. Therefore, this study aims to develop a STEM-based e-module for the Water Quality Management element in the Brackish and Marine Fisheries Agribusiness subject and to determine its validity, practicality, and effectiveness as a digital learning resource for vocational high school students.

Method

This study employed a Research and Development (R&D) approach using the ADDIE development model, which consists of five stages: Analysis, Design, Development, Implementation, and Evaluation. The ADDIE model was selected because it provides a systematic framework for developing and evaluating educational products. The research procedure is presented in Figure 1.

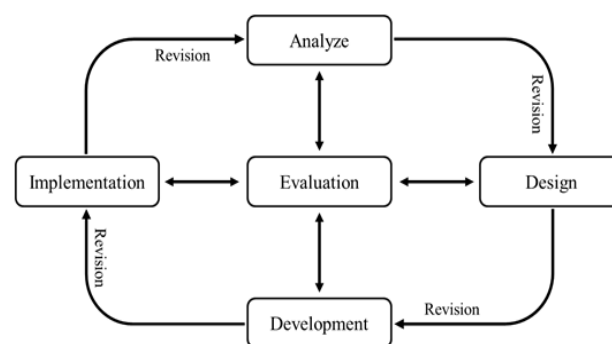


Figure 1. ADDIE Development Model

The research was conducted at SMK Negeri 1 Seri Kuala Lobam, Bintan Regency, Riau Islands Province, Indonesia. The participants consisted of 15 Grade XI students of the Brackish and Marine Fisheries Agribusiness Program and one subject teacher. The product developed was a STEM-based e-module for the Water Quality Management element in the Brackish and Marine Fisheries Agribusiness subject.

The Analysis stage was conducted to identify learning needs, student characteristics, learning problems, and the availability of learning resources. Data were collected through observations, interviews, and questionnaires. The findings from this stage were used as the basis for determining the content and characteristics of the e-module.

The Design stage involved designing the structure and content of the STEM-based e-module. Learning activities were organized according to five stages: Reflection, Research, Discovery, Application, and Communication. At this stage, learning materials, assessment instruments, multimedia components, and navigation systems were also designed.

The Development stage involved producing the STEM-based e-module using Flip PDF Corporate Edition. The developed product incorporated images, videos, animations, hyperlinks, and interactive quizzes. The product was validated by three experts consisting of a material expert, a media expert, and a language expert. The suggestions provided by the validators were used to revise and improve the product before implementation.

The Implementation stage involved testing the validated e-module with 15 Grade XI students and one subject teacher. Students used the e-module during learning activities and completed the assigned tasks and assessments. A pretest was administered before the learning activities and a posttest after the implementation. Teacher and student response questionnaires were also administered to assess the practicality of the e-module.

The Evaluation stage was conducted to determine the validity, practicality, and effectiveness of the developed e-module. Validity was assessed through expert validation, practicality was assessed through teacher and student responses, and effectiveness was evaluated based on the improvement in students' learning outcomes from the pretest to the posttest.

The validity and practicality percentages were calculated using the Formula 1.

$$P(s) = \frac{S}{N} \times 100\% \quad (1)$$

Explanation

P(s) : Percentage of score

S : Total score for each sub-variable

N : Maximum total score

The improvement in students' learning outcomes was determined using the normalized gain (N-Gain) Formula 2.

$$<g> = \frac{T_f - T_i}{SI - T_i} \quad (2)$$

Explanation

<g> : Normalized Gain

Tf : Post-test Score

Ti : Pre-test Score

SI : Ideal Score

To determine the criteria for gain improvement in the following Table 1.

Table 1. Normalize Gain Value

Normalize gain value	Category
$G \geq 0.7$	High
$0.3 \leq g < 0.7$	Moderate
$G \leq 0.3$	Low

(Sugiyono, 2017)

Result and Discussion

Result

The product developed in this study was a STEM-based e-module designed for the Water Quality Management element of the Brackish and Marine Fisheries Agribusiness subject. The e-module integrates STEM principles into learning activities to facilitate students' understanding of water quality concepts and their application in aquaculture practices. To determine the feasibility of the developed product, validation was conducted by media, material, and language experts. The results of the expert validation are presented in Table 2.

Table 2. Results of Expert Validation

Validator	Main Aspects	Obtained Score	Max. Score	Percentage
Media Expert	Completeness, Content, Interface, Interactivity, Technology	105	112	93.8%
Material Expert	Content, Construction, Language, Graphics	93	100	93.0%
Language Expert	Language Rules, Sentence Structure, Communication	42	44	95.5%
Average		240	256	93.75%

The practicality test was conducted to determine the ease of use, time efficiency, and usefulness of the developed STEM-based e-module from the perspectives

of teachers and students. The results of the practicality test are presented in Table 3.

Table 3. Results of Practicality Test

Respondent	Obtained Score	Maximum Score	Percentage	Category
Students	1050	1080	97.2%	Very Practical
Teacher	132	132	100%	Very Practical
Average	1182	1212	98.6%	Very Practical

Based on Table 3, the average practicality score of the STEM-based e-module was 98.6%, indicating a very practical category. The teacher's assessment obtained a percentage of 100%, while students' responses reached 97.2%. These findings indicate that the developed e-module is easy to use, supports learning activities efficiently, and provides substantial benefits in facilitating students' understanding of Water Quality Management concepts.

Table 4. Effectiveness Analysis Results of the Learning Product

Parameter	Value
Mean Pretest Score	73.0
Mean Posttest Score	90.0
Mean N-Gain	0.61 (Moderate)
t_calculated	4.89
t_table (df = 14; $\alpha = 0.05$)	2.145
Significance	$p < 0.05$ (Significant)
Conclusion	Effective Learning Product

Pretest and posttest scores show students' learning outcomes before and after treatment. N-gain indicates improvement level. The t-test was used at $\alpha = 0.05$ (df = 14), and the result shows a significant difference, indicating that the learning product is effective.

Discussion

The findings demonstrate that the STEM-based e-module developed for Water Quality Management can support learning in vocational education by providing interactive, contextual, and technology-supported learning experiences. The integration of science, technology, engineering, and mathematics enables students to connect theoretical concepts with practical applications and problem-solving activities within authentic aquaculture contexts. This finding is consistent with the broader evidence, whose umbrella review of 22 meta-analyses demonstrated that STEM education has positive effects on learning achievement, higher-order thinking skills, and cognitive outcomes. The STEM-integrated e-module could support the development of students' 21st-century skills. Together, these findings suggest that the effectiveness of the developed e-module is related not only to its digital format but also to the integration of STEM principles into the learning activities.

The positive responses from teachers and students further indicate that the e-module is practical and suitable for supporting the learning process. The integration of multimedia elements, including videos, animations, hyperlinks, and interactive exercises, provides students with multiple ways to access and process learning content. These features can facilitate

flexible and independent learning because students can review the material according to their individual learning needs. STEM-based e-module and reported that the resulting digital learning material was valid, practical, and effective in supporting students' critical thinking skills. Electronic modules can support students' learning independence. The effectiveness of interactive digital resources, whose meta-analysis demonstrated a positive effect of interactive media on students' learning outcomes. These findings indicate that the combination of STEM principles, interactive multimedia, and opportunities for independent learning can provide a meaningful structure for student-centered learning.

The effectiveness of the e-module can also be interpreted through the contextual and problem-oriented learning activities embedded in its design. The STEM learning process encourages students to investigate problems, analyze information, and formulate solutions related to water quality management. Such activities provide opportunities for students to construct knowledge through investigation and problem solving rather than relying solely on teacher explanations. STEM-based learning can contribute to the development of students' 21st-century skills, STEM-based engineering design process influenced students' creative and critical thinking abilities. In the present study, the use of STEM principles within an e-module provides a digital environment in which students can engage with learning tasks while connecting conceptual knowledge with practical problems.

The incorporation of authentic aquaculture contexts is another important aspect of the developed e-module. Water quality management is closely related to practical activities in fisheries and aquaculture, making contextual learning particularly relevant to vocational students. By presenting learning problems that reflect realistic aquaculture situations, the e-module enables students to recognize the relationship between classroom knowledge and potential workplace applications. This contextual orientation is consistent with the characteristics of vocational education, in which learning should facilitate the development of knowledge and skills applicable to professional practice. Evidence from vocational education also indicates that technology-supported learning can contribute to practical skill development, for example, found that combining virtual simulations or hands-on activities with instructional video review enhanced vocational students' practical skill performance, while video review also supported self-regulated learning and learning interest. In a related context, Deliana & Anwar (2025) reported that a STEM-oriented project-based learning module supported science and technology skills among students in a vocational high school. These findings

reinforce the relevance of integrating STEM and technology-supported learning within authentic vocational contexts.

The findings further indicate that digital technology can strengthen the learning process when it is integrated with an appropriate pedagogical design. The e-module developed in this study does not function merely as a digital repository of learning materials; rather, it provides structured activities that require students to explore information, interpret problems, and develop solutions. This distinction is important because the educational value of digital learning resources depends not only on the availability of technology but also on how technology is incorporated into meaningful learning activities. Collectively emphasize that digital learning resources can support learning outcomes, self-regulation, and learning interest when they are integrated with appropriate instructional strategies. Furthermore, The application of a STEM-PjBL-based chemistry module increased students' science literacy and learning motivation, demonstrating that STEM-integrated modules can address both cognitive and affective learning outcomes.

Furthermore, the findings reinforce the relevance of STEM-based digital learning for the development of competencies required in contemporary vocational education. Students are increasingly expected to demonstrate not only subject-specific knowledge but also critical thinking, problem-solving, self-regulation, and the ability to apply knowledge in practical situations. Collectively indicate that STEM-based learning can contribute to higher-order thinking and 21st-century competencies, while its potential to support science literacy and learning motivation. Therefore, integrating STEM principles, multimedia features, and authentic vocational contexts in an e-module can provide a learning environment that connects academic concepts with competency-oriented learning.

Overall, the findings indicate that the developed STEM-based e-module is a relevant digital learning resource for Water Quality Management in vocational education. Its potential lies in the integration of STEM principles, interactive multimedia, and authentic aquaculture contexts within a structured learning environment. This combination enables students to connect theoretical knowledge with practical problems while engaging in activities that encourage investigation and problem solving. The findings also suggest that digital learning resources can complement practical vocational learning, particularly when they are designed around authentic tasks and supported by appropriate instructional strategies. However, the implementation of the e-module should also consider students' digital access, teacher readiness, and the availability of supporting technological facilities. Further research

involving larger samples, different vocational contexts, and longer implementation periods is needed to examine the consistency of these findings across different learning environments.

Conclusion

This study developed a STEM-based e-module for Water Quality Management in the Brackish and Marine Fisheries Agribusiness subject. The results indicate that the e-module is valid, practical, and effective in supporting students' learning outcomes. The integration of STEM activities, interactive multimedia, and authentic aquaculture contexts provides a relevant digital learning resource for vocational education. Practically, the e-module can be adapted and implemented as a complementary learning resource in other fisheries vocational high schools with similar learning needs and facilities. Further development should expand the content and interactive features, while future research should involve larger samples and different vocational school contexts to examine its broader applicability.

Acknowledgments

Thank you to all parties who have supported the implementation of this research. We hope this research is useful.

Author Contributions

Conceptualization, methodology, validation, formal analysis, investigation, resources, data curation, writing original draft preparation, and visualization: H.Y. Writing review and editing: H.Y., R. Supervision: H.Y., R. All authors have read and approved the published version of the manuscript.

Funding

The researchers funded this research independently.

Conflicts of Interest

The researchers funded this research independently.

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