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Developing a Digital STEM Module on Dengue Fever: Effects on Critical Thinking and Creativity

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ABSTRACT

Developing students' critical thinking and creativity is a major objective of Indonesia's Merdeka Curriculum, yet classroom learning often remains focused on factual knowledge rather than higher-order thinking. Dengue fever provides an authentic interdisciplinary context for integrating science, technology, engineering, and mathematics (STEM), although few digital STEM modules explicitly support these competencies in formal science education. This study developed a digital STEM module on dengue fever using the ADDIE research and development model and evaluated its validity, practicality, and effectiveness. The implementation employed a one-group pretest–posttest quasi-experimental design involving 30 Grade X students, one science teacher, and three expert validators at SMA Negeri 4 Surabaya. Data were collected through expert validation sheets, practicality questionnaires, classroom observations, pretest–posttest essay tests, and project assessment rubrics. Data were analysed using Aiken's V, descriptive statistics, normalized gain (N-gain), and descriptive effect size. The module demonstrated high validity (Aiken's V = 0.882) and was rated practical by students (83.17%) and very practical by the teacher (93.33%). Classroom implementation was consistently good to very good. Students' mean critical thinking scores increased from 46.10 to 72.87, with a moderate N-gain (0.501). Project assessments also indicated good performance in critical thinking (79.79%) and creativity (81.25%), suggesting that the module effectively supported evidence-based reasoning, problem solving, and innovative solution design. The digital STEM module is a valid, practical, and effective learning resource for contextual science instruction. It provides a promising approach for integrating public health issues into STEM learning while fostering critical thinking and creativity. Further studies should involve larger samples, comparison groups, and longer implementation periods to strengthen evidence of effectiveness.

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1. INTRODUCTION

Dengue remains one of the most persistent vector-borne public health problems in tropical and subtropical regions. Its global burden continues to increase, and Southeast Asia, including Indonesia, remains highly vulnerable because climatic, ecological, and urban conditions support Aedes mosquito breeding and dengue transmission (Alharbi, 2025; Anh et al., 2025; Harapan et al., 2019; Hou et al., 2024; Hu et al., 2025; Noman et al., 2023; Zhang et al., 2025). Although dengue is commonly discussed as a health issue, its causes and prevention also involve biological, environmental, mathematical, technological, and social dimensions. These characteristics make dengue a suitable authentic context for science learning, especially when students are asked to interpret data, evaluate evidence, and design preventive solutions (Halstead, 2019; Misslin et al., 2016; Petersen & Powers, 2016).

The Merdeka Curriculum emphasises critical reasoning and creativity as central learning outcomes through the Pancasila Student Profile. This direction is consistent with international 21st-century skills frameworks that prioritise critical thinking, creativity, collaboration, communication, scientific attitudes, and responsible use of technology (Afandi et al., 2019; Fatonah et al., 2024; Haryani et al., 2021; Mutia & Admawati, 2023; Rejekiningsing et al., 2023). In science education, these competencies require learning activities that move beyond content transmission. Students need opportunities to analyse real problems, construct evidence-based arguments, generate original ideas, and evaluate the usefulness of proposed solutions.

However, the implementation of higher-order thinking in Indonesian classrooms remains uneven. Several studies indicate that classroom assessments and learning tasks often still emphasise recall, recognition, and routine procedures rather than reasoning, evidence evaluation, and creative problem solving (Faisal & Martin, 2019; Fitria & Baroroh, 2023; Haniah et al., 2020; Nurhalizah et al., 2023; Priyatni & Martutik, 2020; Vebrianto et al., 2024). This gap shows that curriculum policy alone is insufficient. Teachers also need learning materials that translate curriculum expectations into practical, contextual, and assessable classroom activities.

Integrated STEM education offers a relevant approach for addressing this need. STEM learning organises science, technology, engineering, and mathematics around authentic problems that require inquiry, modelling, evidence-based reasoning, engineering design, and iterative improvement (Anderson & Li, 2020; English, 2023; Roehrig et al., 2021; Siverling et al., 2021). Digital modules can strengthen this approach when technology is used not merely to display text but to guide students through data analysis, experiment planning, product design, reflection, and formative assessment (Geiger et al., 2023; Mutia & Admawati, 2023; Preetha et al., 2022). Therefore, a digital STEM module has the potential to connect public health issues with measurable learning outcomes in science classrooms.

Previous dengue education interventions have contributed to health knowledge, community awareness, vector monitoring, and prevention behaviour (Bhattarai et al., 2019; Echaubard et al., 2020; Jaroenpool et al., 2024; Overgaard et al., 2022). Nevertheless, many of these programmes were designed mainly as public-health outreach or knowledge-behaviour interventions. They rarely positioned dengue as a formal integrated STEM learning context for upper secondary students, and they often gave limited attention to engineering design, data-based reasoning, creativity, and rubric-based assessment. This creates a research gap: there is still limited evidence on how a dengue-themed digital module can be designed and evaluated as a STEM learning tool within formal science education.

This study addresses that gap by developing a digital STEM module on dengue fever for Grade X science learning under the Merdeka Curriculum. The module transforms dengue learning into a data-to-action cycle in which students analyse dengue-related data, examine environmental factors, design preventive solutions, test natural larvicide ideas, and communicate prevention messages through digital products. The study evaluates the module through validity, practicality, and effectiveness indicators, supported by expert judgement, teacher and student responses, implementation data, pretest-posttest results, and project rubrics (Aiken, 1985; Dapari et al., 2024; Nieveen, 1999; Pratitis & Purwono, 2018). Specifically, the study asks: (1) how valid is the digital STEM module for Grade X dengue-related science learning? (2) how practical is the module for teachers and students? and (3) how effective is the module in supporting students' critical reasoning and creativity?

2. METHODS

This study employed a Research and Development (R&D) approach using the ADDIE model, which consists of Analysis, Design, Development, Implementation, and Evaluation (Branch, 2009). The product developed was a digital STEM module on Dengue Hemorrhagic Fever (DHF) for Grade X science learning in Phase E of the Merdeka Curriculum. To examine the module's effectiveness, the implementation stage used a one-group pretest-posttest quasi-experimental design with the O1-X-O2 scheme. O1 represented the pretest, X represented learning with the digital STEM module, and O2 represented the posttest after the intervention.

The research was conducted at SMA Negeri 4 Surabaya in the science topic "Scientific Solutions for Dengue Fever." This school was selected because it had implemented the Merdeka Curriculum, provided access to digital learning facilities such as Google Classroom and student mobile devices, and was located in a context where dengue prevention was relevant to students' daily lives. The participants consisted of three expert validators, one Grade X science teacher, and 30 Grade X students selected through purposive sampling. The students were included based on their willingness to participate, access to digital learning devices, and teacher recommendation for involvement in project-based STEM learning.

The ADDIE process was implemented in five stages. In the Analysis stage, the research team reviewed Phase E learning outcomes, student characteristics, digital readiness, and the local relevance of dengue-related science learning. In the Design stage, the team prepared learning objectives, concept maps, STEM project activities, digital worksheets, assessment rubrics, and the learning sequence. In the Development stage, the module draft was prepared and reviewed by experts in science content, learning design or educational technology, and digital media. In the Implementation stage, the revised module was tested in two 90-minute meetings. In the Evaluation stage, expert feedback, teacher and student responses, observation results, test scores, and project products were used to assess the module and guide further revisions.

Data were collected using validation sheets, practicality questionnaires, observation sheets, pretest-posttest essay tasks, and project rubrics. The validation sheet assessed content accuracy, STEM integration, alignment with the Merdeka Curriculum, language readability, media design, accessibility, and assessment alignment. The practicality questionnaires measured teacher and student perceptions of ease of use, clarity of instructions, attractiveness, relevance of the dengue context, STEM activity integration, and usefulness for supporting critical reasoning and creativity. The observation sheet recorded learning implementation, student engagement, teacher facilitation, digital module navigation, and evidence of critical reasoning and creative behaviour during project work.

The pretest and posttest consisted of essay and data-analysis tasks related to dengue causes, environmental factors, case interpretation, evidence evaluation, decision making, and solution design. Student project products were assessed using a rubric covering critical reasoning and creativity. Critical reasoning indicators included evidence analysis, argument evaluation, decision making, and reflective thinking. Creativity indicators included originality of ideas, usefulness of the proposed solution, media design quality, and flexibility in improving the solution. Each indicator was scored on a 1-4 scale using predefined descriptors to maintain scoring consistency.

Instrument validity was examined through expert judgement and Aiken's V coefficient (Aiken, 1985). Reliability was strengthened through explicit scoring descriptors, validator review of indicator alignment, and a shared scoring guide for the project rubric. The use of predefined descriptors was intended to reduce scorer subjectivity and maintain consistency in evaluating student products (Pratitis & Purwono, 2018). Because this study was a limited development trial, the reliability procedure focused on content consistency and rubric clarity rather than broad psychometric generalisation.

Ethical considerations were addressed by obtaining school permission before data collection, explaining the purpose and procedures of the study to the teacher and students, and ensuring that student participation was voluntary. Student responses and test scores were used only for research purposes and reported in aggregate form. The learning activities were conducted as part of regular science learning, and the assessment results did not disadvantage students academically.

Data analysis focused on validity, practicality, implementation, and effectiveness. Expert validation data were analysed using Aiken's V and interpreted using validity criteria for educational product development (Aiken, 1985; Nieveen, 1999). Teacher and student practicality responses were converted into percentages and categorised using practicality criteria. Observation data were analysed descriptively as percentages of learning implementation. Effectiveness was examined using normalised gain (N-gain) to determine the magnitude of improvement from pretest to posttest (Hake, 1998). To complement N-gain, a descriptive standardised mean difference (Cohen's d_av) was calculated from the pretest and posttest means and standard deviations. The one-group design was interpreted cautiously because it could not fully control external factors.

3. FINDINGS AND DISCUSSION

This section integrates findings and discussion by presenting each result, interpreting its meaning, and relating it to previous literature. The module was evaluated using three product-quality criteria: validity, practicality, and effectiveness. These criteria were supported by implementation observations and project rubric scores.

3.1 Findings

3.1.1 Validity of the Digital Teaching Module

Expert validation showed that the digital STEM module was valid for limited classroom implementation. The average Aiken's V score was 0.882, with aspect scores ranging from valid to highly valid. This result indicates strong expert agreement that the module was appropriate in terms of content, learning design, media quality, and readability. The validity result is important because a public-health topic such as dengue may lead to misconceptions if biological, environmental, and prevention concepts are not presented accurately. It also confirms that the module's STEM activities were aligned with the Merdeka Curriculum and with the intended competencies of critical reasoning and creativity (Aiken, 1985; Nieveen, 1999; Roehrig et al., 2021).

Table 1. Summary of Module Validity per Aspect (Aiken's V)

Aspect	Number of indicators	Aiken's V (min)	Aiken's V (max)	Average
Language	2	0.833	1.0	0.917
Learning Design	4	0.75	1.0	0.896
Material Suitability	3	0.833	0.917	0.889
Digital Media	3	0.75	0.917	0.833
Total average	12	0.75	1.0	0.882

The highest validity score was obtained in the language aspect, suggesting that the instructions and activity flow were understandable for Grade X students. The digital media aspect had the lowest average among the four aspects, although it remained valid. This finding suggests that future revisions should continue improving navigation, visual clarity, accessibility, and the balance between text, data displays, and interactive tasks. Such refinement is consistent with the principle that digital STEM learning should support inquiry and design activities rather than merely convert printed material into electronic form (Geiger et al., 2023; Preetha et al., 2022).

3.1.2 Practicality and Learning Implementation

Teacher and student responses showed that the module was practical for classroom use. Students rated the module as practical, while the teacher rated it as very practical. These results indicate that the module's instructions, activity sequence, digital format, and dengue context were acceptable for learning. The module functioned as a structured learning package that helped students follow problem orientation, data analysis, solution design, experimentation, communication, and reflection. This is important because STEM learning often becomes difficult to implement when teachers have limited time, students have different readiness levels, and project activities require careful coordination (Mutia & Admawati, 2023; Siverling et al., 2021).

Table 2. Recap of Module Practicality

Respondents	N	Average (%)	SD (%)	Range (%)	Category
Year 10 Students	30	83.17	4.18	70.00–88.33	Practical–Very Practical
Science Teacher	1	93.33	—	—	Very Practical

Observation data also showed that learning implementation was good to very good across the two meetings. This result indicates that the module could be used within the available classroom time, although the implementation duration remained short for a complete STEM design cycle. The slight decrease in implementation percentage from the first to the second meeting may reflect the higher complexity of experiment execution, product refinement, and presentation activities. This interpretation is consistent with STEM learning theory, which views design tasks as cognitively demanding because students must coordinate conceptual understanding, evidence evaluation, technical procedures, and communication decisions (English, 2023; Siverling et al., 2021).

Table 3. Recap of Learning Implementation

Session	Duration	Implementation (%)	Category
1	90 minutes	85.0	Very Good
2	90 minutes	82.50	Good

3.1.3 Effectiveness in Improving Critical Reasoning

The pretest-posttest results showed improvement in students' critical reasoning after using the digital STEM module. The average score increased from 46.10 to 72.87, and the mean N-gain was 0.501, which falls into the moderate category. The descriptive standardised mean difference was large (Cohen's d_av = 3.93). However, this value should be interpreted cautiously because the study used a one-group design and did not include a comparison group. The main interpretation is that students moved from relatively low initial performance to better performance in analysing dengue-related evidence, evaluating environmental factors, and proposing preventive solutions.

Table 4. Summary of Critical Reasoning Improvement (pre–post and N-Gain)

Indicator	Score
N (students)	30
Pre-test mean (SD)	46.10 (4.92)
Post-test mean (SD)	72.87 (8.29)
Mean N-Gain (SD)	0.501 (0.133)
Pretest range	40–55
Post-test range	54–86
Low N-Gain	10% (3 students)
Moderate N-Gain	90% (27 students)
High N-Gain	0% (0 students)
Descriptive effect size (Cohen's d_av)	3.93

The moderate N-gain can be interpreted through the learning mechanism of STEM-based problem solving. The module required students to connect dengue case data, environmental evidence, vector breeding conditions, and prevention strategies. These activities supported the movement from declarative knowledge toward evidence-based reasoning and decision making (English, 2023; Hou et al., 2024; Siverling et al., 2021). However, the gain did not reach the high category. This is reasonable because the intervention lasted only two meetings, while critical reasoning requires repeated practice in interpreting data, defending claims, revising ideas, and reflecting on evidence. Cognitive load may also have affected student performance because students had to learn dengue concepts, use digital tools, conduct project activities, and communicate solutions within a short period. Student readiness in digital learning and project-based learning may further explain why most students achieved moderate rather than high gain (Geiger et al., 2023; Hake, 1998; Mutia & Admawati, 2023).

3.1.4 Project Products, Critical Reasoning, and Creativity

Project rubric results supported the test findings. Students achieved good scores in product-based critical reasoning and creativity. This indicates that the module did not only improve test performance but also encouraged students to apply evidence and generate useful prevention ideas through STEM products and digital campaigns.

Table 5. Project rubric score summary

Component	Average (%)	SD (%)	Range (%)	Equivalent (≈/4)
Product-based critical reasoning	79.79	7.82	62.50–100.00	3.19
Product-based creativity	81.25	6.96	62.50–93.75	3.25

Table 6. Average per rubric indicator (scale 1–4)

Indicator	Average
PK Evidence Analysis	3.23
PK Argument Evaluation	3.13
PK Decision	3.33
PK Reflection	3.07
Authenticity of Ideas	3.33
Creativity Usefulness	3.13
Creativity in Media Aesthetics	3.33
Creativity Flexibility	3.20

The rubric results show that creativity emerged through the design of dengue-prevention solutions and the communication of scientific messages. In STEM learning, creativity is not limited to producing something visually attractive. It involves generating original, useful, and flexible ideas and improving them through evidence-based iteration (English, 2023; Rahimi & Shute, 2021). The module supported these processes by asking students to identify local dengue problems, analyse relevant data, design solutions, test natural larvicide ideas, and communicate prevention messages through posters or videos. This approach extends school-based dengue education beyond knowledge transmission because students were positioned as problem solvers and science communicators (Echaubard et al., 2020; Jaroenpool et al., 2024; Overgaard et al., 2022).

3.2 Discussion

The findings indicate that the developed digital STEM module met the three essential quality criteria for educational products—validity, practicality, and effectiveness—while also supporting students' critical thinking and creativity in learning about dengue fever. Rather than functioning merely as a digital repository of learning materials, the module transformed dengue into an authentic interdisciplinary STEM context where students analysed epidemiological data, interpreted environmental evidence, designed preventive solutions, evaluated natural larvicide alternatives, and communicated scientific information through digital products. This design aligns with the integrated STEM perspective, which emphasises problem solving, engineering design, and evidence-based reasoning within meaningful real-world contexts (English, 2023; Roehrig et al., 2021).

Expert validation demonstrated a high level of agreement regarding the quality of the module, as reflected by the average Aiken's V coefficient of 0.882, indicating that the instructional content, STEM integration, digital media, and learning design were appropriate for Grade X science learning. High validity is particularly important for a health-related topic such as dengue because inaccurate scientific explanations or poorly designed activities may generate misconceptions regarding disease transmission, environmental factors, or prevention strategies. The relatively lower score for digital media, although still within the valid category, suggests opportunities to improve navigation, accessibility, and learner interaction. Previous studies have similarly argued that digital learning environments become pedagogically effective not because they are technology-based, but because they facilitate inquiry, scaffold reasoning, and encourage active student engagement (Geiger et al., 2023; Preetha et al., 2022). Consequently, the present module demonstrates that integrating STEM pedagogy with carefully designed digital learning resources can provide both scientific accuracy and meaningful learning experiences.

The practicality findings further indicate that the module can be realistically implemented in secondary science classrooms. Student responses (83.17%) and teacher evaluation (93.33%) suggest that the learning sequence, digital interface, and project-based activities were perceived as clear, engaging, and manageable. These results imply that the module successfully translated the expectations of the Merdeka Curriculum into classroom practice by providing structured guidance for problem identification, scientific investigation, engineering design, experimentation, and reflection. Importantly, practicality extends beyond ease of use; it also reflects teachers' willingness to adopt instructional innovations within existing classroom constraints. Previous research has shown that STEM implementation frequently encounters challenges related to limited instructional time, varying student readiness, and teachers' confidence in facilitating interdisciplinary learning (Mutia & Admawati, 2023; Siverling et al., 2021). The favourable practicality results therefore suggest that the module offers an operational model capable of reducing these implementation barriers while maintaining instructional quality.

Observation data further reinforce these findings by showing consistently good learning implementation across two instructional meetings. Although implementation slightly declined during the second meeting, this reduction is understandable because students progressed from guided analysis toward more cognitively demanding activities involving experimentation, product refinement, and scientific communication. STEM learning inherently requires students to coordinate conceptual understanding with design thinking, evidence evaluation, collaboration, and iterative problem solving, making later learning stages substantially more complex than introductory activities (English, 2023). Rather than indicating instructional weakness, the slight decline likely reflects the increasing cognitive demands associated with authentic engineering design tasks. This interpretation is consistent with contemporary STEM education literature, which emphasises that productive struggle constitutes an essential component of meaningful learning.

The effectiveness analysis demonstrated a substantial improvement in students' critical thinking following implementation of the module. Mean scores increased from 46.10 to 72.87, while the average normalized gain (N-gain = 0.501) indicated moderate learning improvement. Although the descriptive effect size was large, these findings should be interpreted cautiously because the one-group pretest–posttest design cannot eliminate alternative explanations such as testing effects or maturation. Nevertheless, the consistent improvement across nearly all participants suggests that the module provided meaningful opportunities for students to develop evidence-based reasoning. Rather than memorising biological concepts, students were required to interpret authentic dengue data, evaluate environmental risk factors, justify preventive decisions, and propose scientifically supported interventions. Such learning activities correspond closely with the conceptualisation of critical thinking as disciplined reasoning based on evidence evaluation and informed decision-making (English, 2023; Siverling et al., 2021).

The moderate rather than high N-gain is also theoretically meaningful. Critical thinking represents a higher-order cognitive competence that develops gradually through repeated opportunities to analyse information, defend arguments, revise explanations, and reflect upon evidence. In the present study, the intervention was implemented over only two classroom meetings, limiting opportunities for iterative reasoning and sustained cognitive development. Furthermore, students simultaneously learned scientific concepts, digital technologies, project-based learning procedures, and collaborative problem-solving strategies, potentially increasing cognitive load during instruction. Similar observations have been reported in digital STEM studies, where short-duration interventions often produce moderate gains despite demonstrating substantial educational potential (Geiger et al., 2023; Hake, 1998; Mutia & Admawati, 2023). Consequently, longer implementation periods involving multiple engineering design cycles may generate stronger improvements in higher-order thinking.

The project assessment provides complementary evidence that the module successfully promoted creativity alongside critical thinking. Students achieved good performance across all creativity indicators, including originality, usefulness, flexibility, and media design quality. These findings suggest that creativity emerged not simply through artistic production but through designing scientifically justified solutions that addressed authentic local health problems. Contemporary creativity research increasingly recognises creativity as the capacity to generate original and useful solutions supported by iterative refinement rather than spontaneous idea generation alone (Rahimi & Shute, 2021). Within this study, students continuously refined their prevention strategies by integrating scientific evidence with engineering design, demonstrating that creativity and critical thinking functioned as complementary rather than independent competencies. This finding extends previous dengue education research, which has primarily focused on improving health knowledge and preventive behaviour rather than cultivating higher-order cognitive skills through integrated STEM learning (Echaubard et al., 2020; Jaroenpool et al., 2024; Overgaard et al., 2022).

Overall, this study contributes both practically and theoretically to science education. Practically, it offers a validated digital STEM module that teachers can readily implement to integrate public health issues into contextual science learning under the Merdeka Curriculum. Theoretically, the study proposes a data-to-action STEM learning model, in which students progress systematically from analysing authentic scientific data to designing evidence-based solutions and communicating preventive actions through digital media. This instructional pathway demonstrates how public health contexts can simultaneously strengthen scientific literacy, critical thinking, creativity, and problem-solving within integrated STEM education. Nevertheless, because the study employed a single-group design with a relatively small sample from one school, future research should adopt stronger quasi-experimental or experimental designs involving larger and more diverse populations, longer intervention periods, and longitudinal assessment to establish stronger causal evidence and examine the sustainability of learning outcomes.

4. CONCLUSION

This study developed a digital STEM module on dengue fever for Grade X science learning under the Merdeka Curriculum and demonstrated that the module is valid, practical, and effective in fostering students' critical thinking and creativity. Expert validation confirmed the module's high quality, while positive teacher and student responses indicated its practicality for classroom implementation. The findings further showed moderate improvement in students' critical thinking and good achievement in project-based critical thinking and creativity, suggesting that integrating authentic public health issues into digital STEM learning can promote evidence-based reasoning, problem solving, and creative solution design. Despite these promising outcomes, the study has several limitations, including the use of a one-group pretest–posttest design without a comparison group, a relatively small sample drawn from a single school, and a short intervention period, which limit causal inference and the generalizability of the findings. Therefore, future research should employ more rigorous experimental or quasi-experimental designs with control groups, involve larger and more diverse participant populations across different educational settings, extend the duration of implementation, and investigate the long-term effects of digital STEM learning on critical thinking, creativity, scientific literacy, and students' engagement in solving authentic socio-scientific problems.

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