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Integration of Computational Thinking in a Thermodynamics E-Module on the Ahmaddahlan.NET Website as an Effort to Strengthen Digital Literacy

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Abstract

The rapid advancement of digital technology necessitates learning materials that not only support instructional processes but also foster higher-order thinking skills among university students. This study aims to develop a Thermodynamics e-module grounded in computational thinking (CT) principles and integrated into the Ahmaddahlan.NET learning platform to enhance students' digital literacy. The urgency for this development stems from the limitations of conventional thermodynamics instruction, which often struggles to connect fundamental concepts with empirical applications and computational analysis. As a result, an interactive, technology-based instructional approach is essential for improving students' competency attainment. The research utilized the ADDIE Research and Development (R&D) framework, encompassing five stages: analysis, design, development, limited implementation, and evaluation. The e-module was designed around four core CT components decomposition, pattern recognition, abstraction, and algorithmic thinking. A limited trial was conducted with first-semester students enrolled in Basic Physics. Data were collected through expert validation and student response questionnaires assessing clarity, readability, and ease of access. Expert validation yielded a score of 95.1%, categorizing the e-module as highly feasible. In terms of practicality, user responses reached 88.1%, indicating that the interactive interface, intuitive navigation, and integration of digital content provided a positive learning experience. The module's effectiveness was reflected in students' digital literacy outcomes, which achieved a "good" category score of 79.8%, encompassing digital skills, digital security, digital culture, and digital ethics and responsibility. Overall, the findings demonstrate that the developed CT-based e-module effectively supports 21st-century learning demands and has strong potential as an innovative instructional resource in higher education settings. Its integration of computational thinking and digital literacy provides a robust foundation for modernizing thermodynamics instruction.

Keywords: *E-Module, Computational Thinking, Thermodynamics, Digital Literacy, 21st-Century Learning*

Introduction

Global transformations in education demand that higher education institutions provide learning experiences that are not only informative but also transformative, ensuring that students are equipped to navigate a workforce increasingly intertwined with digital technologies. The rapid development of digital technology has driven the education sector to adopt more adaptive, competency-oriented learning approaches. In the context of the Fourth Industrial Revolution, thermodynamics learning requires a major shift from traditional lecture-based methods toward approaches that integrate 21st-century skills critical thinking, creativity, communication, collaboration, and digital as well as computational literacy. Limited utilization of

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interactive learning technologies often results in students struggling to connect foundational concepts including thermodynamic laws, properties of matter, energy balance, and adiabatic or isothermal processes with real phenomena or computational data analysis.

A growing body of research highlights that physics instruction, particularly on abstract topics such as thermodynamics, is more effective when students are provided with opportunities to explore simulations, data visualizations, and modeling activities. These tools help concretize difficult-to-visualize concepts through dynamic computational representations (Weller et al., 2021). Within this context, Computational Thinking (CT) serves as an essential cognitive framework for designing digital learning. CT extends beyond programming skills; it encompasses systematic ways of reasoning through decomposition, abstraction, pattern recognition, and algorithmic design, all of which are highly relevant to scientific and engineering problem-solving.

Recent literature reviews indicate that CT significantly improves students' abilities in data analysis, problem-solving, and scientific reasoning. Its integration into science learning supports students in understanding complex concepts through modeling, simulation, and computational representation (Karakaş et al., 2023). Meta-analytical findings further confirm that CT enhances critical thinking, learning motivation, and digital readiness, making it particularly relevant for higher education environments that demand technological and data literacy (Apriana et al., 2024). Consequently, there is a pressing need for learning media capable of accommodating CT requirements while presenting thermodynamics content systematically and in an exploratory format.

Parallel to this, the rise of interactive web-based e-modules has opened significant opportunities for more flexible, accessible, and competency-based physics learning. Various reviews and meta-analyses consistently show that e-modules and similar digital learning resources enhance learning outcomes and scientific process skills more effectively than traditional methods (Fadillah et al., 2024). In practice, e-modules equipped with interactive simulations, animations, and automated evaluation features have been shown to increase motivation, engagement, and conceptual understanding of complex physics topics, as demonstrated in research on the effectiveness of PhET simulations (Banda et al., 2023). Digital pedagogy–oriented e-modules that incorporate videos, simulations, and virtual laboratories also support deeper self-paced learning, such as analyzing thermodynamic energy graphs, modeling expansion and compression processes, or exploring Carnot, Otto, and Rankine cycles findings supported by studies on interactive physics e-module development (Cynthia et al., 2023).

Such interactivity enables students not only to understand concepts mathematically but also to develop scientific intuition and computationally driven analytical skills. This is reinforced by research showing that interactive digital modules significantly enhance students' critical thinking compared to conventional materials (Pitorini et al., 2025). Recent meta-analyses similarly confirm the effectiveness of e-modules in strengthening critical thinking and scientific literacy (Marlina et al., 2025). These findings suggest that an e-module's success depends not only on content quality but also on students' ability to utilize digital technologies effectively during learning.

Strengthening digital literacy is also a strategic priority in higher education. Outlines five essential components: access, evaluation, content creation, communication–collaboration, and digital safety (UNESCO, 2018). These components are highly relevant in physics learning, where students must not only master scientific concepts but also locate and evaluate data independently, assess source credibility, generate computer-based visualizations or models, and collaborate effectively within digital environments. Researcher emphasize that digital literacy extends beyond operating devices; it encompasses epistemic competencies in interpreting, constructing, and communicating knowledge derived from digital data (Spante et al., 2018).

Integrating UNESCO's digital literacy framework with CT in a Thermodynamics e-module is therefore a strategic approach to ensuring that students understand physics concepts while engaging with digital technologies critically, safely, and productively. From an instructional design perspective, existing research on CT implementation in higher education highlights the importance of measurable assessment instruments to evaluate CT development. Digital platforms such as web-based learning systems have been shown to effectively support process-oriented assessments, including analysis of activity logs, algorithm structure evaluations, and assessments of students' problem-solving steps.

Research in Indonesia remains limited to developing e-modules that evaluate user acceptance or cognitive understanding, while assessments of digital literacy and computational abilities are often overlooked. Thus, the development of a CT-based Thermodynamics e-module on the Ahmaddahlan.NET website offers substantial contributions. It emphasizes conceptual understanding while providing digital exploration tools, simulations, CT-oriented assessments, and UNESCO digital literacy indicators to capture students' digital competence more comprehensively. This gap specifically the limited integration of CT and digital literacy assessmentsreinforces the need for more comprehensive and structured learning innovations.

The novelty of this research lies in the simultaneous integration of CT, UNESCO digital literacy indicators, and thermodynamics content within a web-based interactive e-module. Through this integrated approach, the e-module functions not only as a learning resource but also as a platform for cultivating scientific, digital, and computational thinking. Additionally, this study evaluates the module's validity, practicality, and effectiveness through expert review, limited trials, and field testing, producing a replicable model for CT-based physics e-module development. By grounding the design in pedagogical theory, CT principles, and UNESCO digital literacy dimensions, the module aims to foster reflective, collaborative, creative, and data-driven competenciesskills essential for navigating the dynamics of the global digital ecosystem and the technology-driven professions of the future. This novelty is particularly significant given the scarcity of physics learning resources in Indonesia that explicitly integrate CT and digital literacy indicators within a single platform. Accordingly, this research helps fill that gap and offers a model for technology-enhanced physics learning that can serve as a national reference.

Method

This study employed the ADDIE development model Analysis, Design, Development, Implementation, and Evaluation (Sutrisno et al., 2024). The model was selected for its systematic workflow and flexibility, which allow iterative refinement at each stage to ensure that the resulting e-module meets pedagogical, technical, and user-centered standards. ADDIE is widely used in technology-based instructional design because it effectively integrates pedagogical principles with the needs of digital and computational literacy. The ADDIE stages include analysis of needs, systematic design, material development, implementation in learning settings, and comprehensive evaluation of outcomes.

1. ***Analysis:*** The analysis phase identified the needs of students and lecturers regarding digital learning materials and examined the characteristics of Basic Physics content relevant to Computational Thinking (CT). Challenges students face in learning thermodynamics were

also analyzed to ensure the e-module directly addresses user needs. Curriculum analysis and literature review were conducted to align the e-module with course learning outcomes.

2. ***Design:*** The design phase involved structuring the e-module content, integrating CT components—decomposition, pattern recognition, abstraction, and algorithmic thinking—and developing the interface for the Ahmaddahlan.NET platform. Modern instructional design principles were applied to ensure the material was engaging, interactive, and accessible. Each unit was aligned with CT logic to support both conceptual understanding and data-driven problem-solving. The interface was designed to be intuitive, responsive, and compatible with multiple devices.
3. ***Development:*** In this phase, the e-module was produced according to the approved design and subsequently validated by experts. Expert feedback ensured that the content, visual design, and interactivity met pedagogical and technical standards. Revisions were made to improve content clarity, interface quality, and digital instructional features in accordance with student characteristics.
4. ***Implementation:*** A limited trial was conducted with 33 Physics Education students at the Faculty of Mathematics and Natural Sciences, Universitas Negeri Makassar, who had completed the Basic Physics course. This trial aimed to evaluate the practicality of using the e-module, the quality of its display and content presentation, and its potential to enhance students' digital literacy. The results provided an initial overview of the e-module's feasibility as a technology-based learning medium that supports independent learning. It also provided insights into technical and pedagogical issues that may arise in broader implementation.
5. ***Evaluation:*** The final stage assessed the e-module's validity, practicality, and effectiveness using three instruments: expert validation sheets, student perception questionnaires, and a digital literacy questionnaire. Expert validation measured validity and practicality, while student perceptions assessed usability and interactivity. Effectiveness was evaluated through a digital literacy instrument based on UNESCO indicators: digital skills, digital safety, digital culture, and digital ethics. This framework enabled a comprehensive assessment of both technical and ethical dimensions of digital competence.

Data were analyzed quantitatively using descriptive statistics. Expert validation results were interpreted using criteria adapted from (Riduwan, 2013): 81–100% (very valid), 61–80% (valid), 41–60% (fair), 21–40% (poor), and 0–20% (invalid). Student perceptions and digital literacy scores were reported in mean values and percentages to determine the e-module's practicality and effectiveness. This evaluation process provides a comprehensive overview of product quality and its potential for wider implementation in technology-enhanced physics learning, and it serves as a basis for future development recommendations.

Result

The CT-based Basic Physics e-module developed on the Ahmaddahlan.NET website focused on Thermodynamics, covering topics such as heat energy, the first and second laws of thermodynamics, and the efficiency of heat engines. Validation was conducted by three experts: two instructional media specialists and one physics content expert. The validation assessed content quality, conceptual accuracy, visual design and interactivity, and integration of CT components (decomposition, pattern recognition, abstraction, and algorithmic thinking).

Table 1. *Expert Validation of the CT-Based Thermodynamics E-Module on Ahmaddahlan.NET*

No	Aspect	Total Score	Percentage (%)
1	Module Content	70	97,2%
2	Clarity of Learning Objectives	35	97,2%
3	Module Structure and Organization	34	94,4%
4	Visual and Media Design	44	91,7%
5	Learning Activities	35	97,2%
6	Evaluation and Feedback	44	91,7%
7	Usability	45	93,8%
8	Security and Technical Aspects	46	95,8%
9	Innovation and Creativity	35	97,2%
Overall Mean		-	95,1%

Table 1 presents the expert validation results. The overall average score was 95.1%, indicating that the e-module is highly feasible. Experts highlighted that presenting thermodynamic concepts through interactive simulations and algorithmic thinking exercises helped students understand the relationships between energy, work, and entropy more concretely. The e-module's practicality was assessed using a student perception questionnaire administered to 35 Physics Education students at FMIPA Universitas Negeri Makassar. Students studied Thermodynamics topics and completed CT-based exercises, such as modeling energy flows and designing heat engine efficiency algorithms.

Table 2. *Student Perception of the CT-Based Thermodynamics E-Module on Ahmaddahlan.NET*

No	Assessment Aspect	Total Score	Percentage (%)
1	Ease of Access and Navigation	179	89,5
2	Learning Design and Interactivity	176	88,2
3	Usefulness for Conceptual Understanding	173	86,7
Overall Mean		-	88,1

As shown in Table 2, the practicality assessment indicated that students rated the CT-based Thermodynamics e-module as highly practical, with an overall score of 88.1%. Students appreciated the interactive interface, Carnot cycle visualizations, and simulations that enabled exploration of the relationships between heat, work, and engine efficiency. They also reported that the CT-based exercises facilitated systematic problem-solving in thermodynamics. Effectiveness was measured using a digital literacy questionnaire based on UNESCO indicators (2023). This instrument evaluated the extent to which the e-module supported students' digital competence in a science and technology learning context.

Table 3. *Student Digital Literacy Based on UNESCO Indicators (2023) for the CT-Based Thermodynamics E-Module*

No	Digital Literacy Dimension	Total Score	Percentage (%)
1	Digital Skills	443	83,9
2	Digital Safety	393	74,4
3	Digital Culture	433	82,0
4	Digital Ethics	312	78,8
Overall Mean		-	79,8

As shown in Table 3, the use of the CT-based Thermodynamics e-module had a positive impact on students' digital literacy, with an overall score of 79.8%, classified as **good**. The highest improvements were observed in Digital Skills and Digital Culture, reflecting students' ability to analyze thermodynamics problems digitally and to collaborate effectively within the Ahmaddahlan.NET online environment.

Discussion

The development of a Thermodynamics e-module based on Computational Thinking (CT) on the Ahmaddahlan.NET website represents a strategic step in improving the quality of Basic Physics learning in the digital era, especially as students increasingly rely on technology devices in their learning process. The need for interactive, flexible, and easily accessible digital learning media has become increasingly urgent due to the changing characteristics of today's learners, who tend to prioritize quick access and strong information visualization (Muslimin et al., 2024; Godsk et al., 2025). This e-module integrates CT principles, emphasizing problem decomposition, pattern recognition, abstraction of concepts, and algorithm design. Therefore, students not only learn thermodynamics conceptually but also connect it with computational thinking processes relevant to academic needs in the Industry 4.0 era (Grover et al., 2018). Integrating CT concepts in thermodynamics has been shown to provide more meaningful learning opportunities, as students can visualize relationships between variables, such as changes in internal energy, entropy, thermodynamic cycles, or isothermal processes, through graphical representations, digital models, and interactive simulations. Research by (Irvani et al., 2024; Weller et al., 2021) confirms that integrating Computational Thinking into physics learning enhances modeling skills, digital representation, and conceptual understanding through simulation activities.

Research results indicate that this e-module is valid in terms of content, instructional design, and interface, with an overall validity score of 95.1%, demonstrating alignment with modern multimedia learning principles. Furthermore, the use of infographics and visual representations helps reduce students' cognitive load, allowing them to construct understanding gradually, in line with modern multimedia-based learning models (Liu, 2024). The application of CT in learning thermodynamics also equips students with skills to develop problem-solving algorithms, such as analyzing the efficiency of heat engines or predicting variable changes in isobaric and adiabatic processes. Thus, CT implementation supports the development of scientific reasoning and systematic thinking (Irvani et al., 2024).

Beyond validity, the e-module also demonstrates high practicality. Student assessments show an overall practicality score of 88.1%, with the highest ratings in ease of access, intuitive navigation, and effectiveness of automatic evaluation features. This makes the e-module easier to use and increases motivation for independent learning, as supported by research on interactive digital design in higher education (Estrada et al., 2022; Sholeh et al., 2023). Thermodynamics simulations and CT-based exercises allow students to build spiral learning, progressing from visual exploration and mathematical analysis to algorithmic problem-solving, which is crucial in online or hybrid learning contexts.

The effectiveness of this e-module is also reflected in improved digital literacy among students, aligned with UNESCO's digital literacy framework, which includes digital skills, digital culture, and digital ethics and safety. When students engage in activities such as analyzing experimental data, creating digital graphs, collaborating synchronously and asynchronously, and developing algorithms to solve physics problems, they enhance high-level digital literacy skills essential for today's professional environment (Getenet et al., 2024).

Students using this e-module show improvements in identifying patterns of thermodynamic variable changes, predicting system behavior, and systematically designing problem-solving strategies. This indicates that CT not only strengthens conceptual understanding but also develops higher-order thinking skills (Rosandhi et al., 2024; Walimudin et al., 2023). Additionally, integrating digital simulations into thermodynamics allows students to link abstract physics theory with concrete computational representations, enabling them to understand physical phenomena through variable manipulation and data-based interpretation (Tuyizere et al., 2023).

A significant contribution of the CT-based e-module is the enhancement of students' digital literacy. According to UNESCO's framework, digital literacy includes digital skills, digital culture, and digital ethics and safety. The study shows that students' digital skills scored 83.9%, digital culture 82.0%, digital ethics 78.8%, and digital safety 74.4%. Students can analyze experimental data, create digital graphs, collaborate online, and develop algorithms to solve physics problems, improving their digital literacy to a level relevant to Society 5.0. Overall, the CT-based Thermodynamics e-module on Ahmaddahlan.NET can be considered a pedagogical innovation that significantly contributes to improving physics learning in the modern era. Its flexible, interactive, and multidimensional competency-oriented nature has great potential for replication in other digital learning materials, serving as a model for technology-based future education (Putra et al., 2024; Paputungan et al., 2023).

Integrating CT principles in the e-module not only strengthens conceptual understanding of thermodynamics but also changes how students interact with learning materials. Systematic problem-solving through algorithm-based approaches encourages students to enter a more exploratory digital inquiry phase. This approach broadens students' analytical abilities, as seen in CT implementation in other STEM disciplines emphasizing pattern recognition and algorithmic refinement. These findings align with (Tariq et al., 2025), showing that CT consistently enhances higher-order thinking through pattern analysis, abstraction, and algorithm design in digital contexts. Furthermore, (Diani et al., 2024) reinforce that CT application in physics learning encourages students to develop more structured, data-driven problem-solving strategies. Thus, the e-module supports conceptual understanding while providing a self-paced, reflective, discovery-based learning space, consistent with modern constructivist theory and technology-assisted inquiry-based learning, where students build understanding through guided independent exploration.

In conclusion, the development of a CT-based Thermodynamics e-module on the Ahmaddahlan.NET platform makes an important contribution to transforming physics learning in the digital era. The integration of CT, interactive visualization, and data-driven analytical activities enables students to build deeper, structured conceptual understanding. Strengthened digital literacy from e-module use demonstrates that students can not only access and utilize technology but also interpret digital information, process simulation data, and make independent scientific decisions. With flexible, adaptive instructional design suitable for hybrid and online learning, this e-module has the potential to serve as an innovative model applicable to other courses. In addition to enhancing the effectiveness of Thermodynamics learning, it opens opportunities for further development, such as using artificial intelligence for automated assessment and learning analytics. Therefore, this study not only produces valid, practical, and effective digital learning materials but also provides new directions for developing technology-based physics education responsive to 21st-century competency needs.

Conclusion

The findings indicate that the development of the Computational Thinking (CT)-based Thermodynamics e-module has successfully met the criteria of feasibility, practicality, and effectiveness as a digital learning resource for students. In terms of validity, the e-module was rated highly feasible, as the content is accurate, well-structured, and contextualized, effectively linking thermodynamic concepts to real-world phenomena relevant to students. The integration of CT elements enhances learning by promoting algorithmic thinking, systematic problem-solving, and visual representations that facilitate the comprehension of abstract concepts. The practicality of the e-module is reflected in students' positive responses to its user interface, ease of navigation, and interactive features that support independent learning. Its effectiveness is demonstrated by improvements in students' digital literacy, categorized as good based on UNESCO indicators, including digital skills, digital safety, digital culture, and the ethical and responsible use of digital technology. Overall, the e-module proves to be a modern educational tool that not only reinforces conceptual understanding but also enhances essential digital competencies for 21st-century learning.

Practically, these findings suggest that CT-based e-modules can be widely adopted as alternative digital learning resources for Thermodynamics and other physics courses, particularly to support self-directed learning, project-based learning, and authentic assessments emphasizing computational thinking processes. However, this study has limitations, including a small-scale trial, dependency on students' access to digital devices, and the lack of full integration with institutional Learning Management Systems (LMS). Future recommendations include the development of an advanced e-module with broader content coverage, expansion of trials across diverse contexts and student populations, integration with campus digital learning environments, and the addition of adaptive features to tailor difficulty levels according to individual student abilities, thereby further enhancing learning effectiveness.

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