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Assessing Computational Thinking Skills: Physics Computational Test based on Scratch Program for High School Students

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Abstract: Computational thinking ability has become one of the primary focuses in science education, including physics, as a response to the challenges of the Fourth Industrial Revolution. Integrating computational physics concepts into learning requires relevant and comprehensive assessment tools to measure students' abilities. A programming-based test instrument using Scratch was designed to evaluate computational thinking skills through programming activities linked to physics principles. This study aims to develop a Scratch-based test instrument to assess students' computational thinking abilities on the topic of sound waves within secondary-level physics education. The research employs a development method based on the stages outlined by Borg & Gall, which include: (1) analysis of potential and problems; (2) data collection; (3) product design; (4) design validation and revision; (5) product trials; and (6) data analysis and reporting of results. The trial subjects involved 99 students. The developed test instrument consists of 21 items. Based on the content validity test, 87.55% was obtained, indicating the instrument's feasibility. The instrument's reliability was measured using Cronbach's Alpha coefficient, yielding a value of 0.781, which falls into the high category. Overall, this Scratch-based computational physics test instrument is declared suitable for evaluating students' computational thinking abilities with physics content.
***Keywords**:* Computational Thinking Skills; Scratch; Physics Test

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Introduction

The rapid advancement of technology in the era of the Fourth Industrial Revolution has brought significant changes to various aspects of life, including education (Kravchenko et al., 2022; Uzumcu & Acilmis, 2024). This transformation has influenced learning paradigms, particularly in science fields like physics. (Bitzenbauer, 2023; Negoro et al., 2020). Advancements in digital technology have transformed how information is delivered and enabled complex learning activities to be reduced into efficient virtual simulations. In this context, physics education has greatly benefited from integrating technology, particularly regarding information accessibility and developing students' computational thinking skills.

Easy access to information through digital sources allows students to acquire learning materials quickly and efficiently. For instance, searching for basic physics concepts to complex formulas no longer relies entirely on printed books, which often take longer ca(Calavia et al., 2021; Tang et al., 2022). However, for technology to be used effectively in learning, students need to have the appropriate awareness and strategies to utilize it. One of the primary skills that has become a key focus is computational thinking, which encompasses technology-based problem-solving skills (Emara et al., 2021; Li et al., 2020).

Computational thinking is a core skill that is increasingly emphasized in modern curricula, as implemented in the United States, the United Kingdom, and Japan (Haseski et al., 2018; Israel-Fishelson & Hershkovitz, 2022; Tsai et al., 2021). This ability is related to technological proficiency and integrating scientific concepts, including physics, through computational approaches. This integration involves transforming students' ways of thinking, where physics concepts are explored through algorithmic approaches utilizing programming platforms such as Scratch (Jiang & Li, 2021; Stewart & Baek, 2023).

Scratch, as a widely adopted visual programming platform, offers a unique and pedagogically sound approach to learning physics. It utilizes puzzle-like command blocks that allow students to design simulations, interactive animations, and mathematical models related to scientific concepts, without the prerequisite of mastering complex textual programming languages. Compared to other programming environments, Scratch is particularly advantageous for educational purposes due to its intuitive drag-and-drop interface, low cognitive load for beginners, and alignment with constructivist learning principles. Its design specifically targets novice learners, especially at the K–12 level, making it more accessible than other general-purpose platforms such as Python or JavaScript (Topali & Mikropoulos, 2023). Furthermore, Scratch is supported by a large online community and an abundance of open educational resources, which facilitates both independent exploration and classroom integration. Through this platform, students can engage more actively with abstract physics concepts in a visual and interactive manner, thereby fostering technological literacy, promoting computational thinking, and deepening conceptual understanding (Negoro et al., 2023; Rusilowati et al., 2020).

However, a challenge arises in evaluating computational thinking skills that are integrated with physics content. Most existing assessment instruments currently take the form of questionnaires or surveys, which tend to measure cognitive aspects at a lower level. Additionally, many instruments do not fully integrate physics content into the evaluation, resulting in less comprehensive outcomes (Banda & Nzabahimana, 2021; Rusilowati et al., 2022). To address this challenge, it is necessary to develop a test instrument that measures students' computational thinking skills while also considering their mastery of physics concepts.

Several researchers have researched the evaluation of computational thinking in physics learning. Some studies have developed instruments to measure Computational Thinking Skills with an orientation toward physics learning (Lathifah et al., 2023; Tsai et al., 2021; Weintrop et al., 2021). However, these instruments are generally questionnaires or surveys that only reveal aspects of technology implementation without delving into the depth of physics content. Additionally, using computer programming as a basis for evaluation is rarely found in previous research literature.

Based on the literature review, it can be concluded that research on the evaluation of computational thinking in physics learning is still limited. Most previous studies focused on developing questionnaire- or survey-based instruments, which tend to overlook higher cognitive levels and the deep integration of physics content. Additionally, the use of computer programming as an evaluation medium has not been extensively explored, even though platforms like Scratch have significant potential for holistically measuring computational thinking.

There is a growing need for assessment tools that integrate computational thinking with physics content to evaluate students’ higher-order cognitive skills. However, existing instruments often rely on textual programming, which can bias results due to varying levels of coding proficiency. This study addresses that gap by developing a Scratch-based test instrument focused on sound wave concepts. By utilizing Scratch’s visual and beginner-friendly interface, the instrument allows for meaningful programming tasks while minimizing bias from textual coding limitations. The result is a more objective and representative tool for assessing students’ conceptual understanding and computational thinking in physics.

This study aims to develop a novel test instrument based on Scratch programming to assess students' computational thinking abilities within the context of physics, specifically on the topic of sound waves. Unlike conventional survey-based instruments that primarily measure self-reported perceptions or general understanding, this instrument incorporates performance-based tasks that require students to apply computational thinking through visual programming. Scratch was selected as the development platform due to its intuitive, block-based interface, which enables students to construct algorithms without the need for advanced textual coding skills. This approach minimizes potential measurement bias and allows for a more authentic assessment of students' problem-solving and conceptual reasoning in physics. The resulting instrument offers a more comprehensive and contextually relevant evaluation tool, aligning with the evolving demands of physics education in the digital age.

Method

This research is categorized as educational development research or Research and Development (R&D). R&D is a process that develops and validates products (Sugiyono, 2010). The product being developed in this study is a Scratch programming-based test instrument designed to evaluate students' computational thinking skills in physics content related to sound waves. The test is structured in a multiple-choice format, with Scratch programming integrated as the evaluation medium.

The development of the test instrument refers to the R&D stages, which are a reduced version of the Borg & Gall model, incorporating six core steps while still considering the essence of the development and research process (Negoro et al., 2020). The main stages are: (1) analysis of potential and problems, (2) data collection, (3) product design, (4) design validation through expert judgment, (5) field trials, and (6) analysis of trial results and reporting. The initial research stage was conducted to identify the need for physics learning evaluation tools integrated with computational technology. The data from this stage served as the basis for designing a relevant test instrument.

The developed test instrument covers the topic of sound waves. The test consists of 21 multiple-choice questions, each with five answer options. The answer choices are designed with distractors to reduce the likelihood of students answering randomly without in-depth analysis. Each question is structured to reveal students' understanding of physics concepts through Scratch programming activities. This test instrument was developed by adapting aspects of computational thinking skills relevant to science education, as previously explored in several prior studies (Palop et al., 2025). The aspects of Computational Thinking Skills are assessed through multiple-choice questions, with indicators that can be seen in Table 1.

Table 1. Question Indicators for Each Aspect of Computational Thinking Skills

Aspect	CT Indicator	Sample Question Indicators
Decomposition	Break down complex problems into smaller, manageable parts relevant to physics simulations.	Students select the correct sequence of steps to break down the process of creating a wave simulation using Scratch blocks.
Pattern Recognition	Detect recurring patterns or structures within physics data and programming commands.	Students identify the appropriate block patterns to calculate physics parameters such as frequency or wavelength.
Abstraction	Identify essential features and represent them while ignoring irrelevant details.	Students determine the most appropriate Scratch blocks to represent a simple model of harmonic oscillation.
Redefine Problems	Reformulate or optimize a problem-solving approach to improve efficiency or clarity.	Students select a more efficient approach to simulate the phenomenon of standing waves.
Algorithmic Design	Design step-by-step procedures or algorithms to solve specific physics problems via programming.	Students select the correct sequence of Scratch blocks to simulate wave propagation with specific parameters.
Strategic Decision Making	Evaluate and decide on the best strategies or block combinations to model relationships in physics.	Students evaluate the most effective combination of Scratch blocks to represent the frequency and wave speed relationship.
Data Representation	Translate physics data into appropriate visual or graphical formats within programming environments.	Students select the option demonstrating the representation of physics data (e.g., wave amplitude) as a dynamic graph.

Before the field trials, the test instrument was evaluated for its feasibility through expert judgment. This evaluation was conducted by experts to assess the content validity of the instrument from various aspects, including material relevance, content completeness, and the instrument's ability to reveal mastery of physics concepts. The results of the expert judgment assessment were analyzed using Formula 1.

$$P = \frac{f}{N} \times 100\% \; . \tag{1}$$

Explanation:
P: Assessment percentage,
f: Score obtained,
N: Total possible score.

The percentage analysis results are then classified based on feasibility criteria, as shown in Table 2. These criteria are used to determine whether the test instrument is suitable for use in field trials.

Table 2. Feasibility Criteria

P (Percentage in %)	Feasibility Category
$85 < P \leq 100$	Very Feasible (Highly Valid)
$70 < P \leq 85$	Feasible (Valid with Minor Revisions)
$50 < P \leq 70$	Moderately Feasible (Needs Major Revisions)
$1 < P \leq 50$	Not Feasible (Invalid)

(Negoro et al., 2020)

The field trial was conducted at two senior high schools, including SMA Negeri 3 Semarang, with a total of 99 students participating as test subjects. These participants represented diverse academic backgrounds and learning experiences within the secondary education level, providing a relevant context for evaluating the instrument. The primary aim of the trial was to collect data on the psychometric properties of the test instrument, including item difficulty, discrimination power, and students' conceptual understanding of sound waves. The resulting data were analyzed to assess the instrument's effectiveness and to ensure its suitability for broader application in physics education.

A reliability analysis of the instrument was performed using Cronbach's Alpha formula to measure its internal consistency. Reliability is one of the key indicators for assessing the dependability of the test instrument in consistently measuring students' abilities. Additionally, students' mastery profiles of sound wave concepts were described quantitatively to provide a clearer picture of student learning outcomes.

Results

The main product resulting from this research is the Scratch-based Physics Computational Test. This test instrument measures two main aspects: students' computational thinking skills in the context of computational physics and their mastery of physics concepts related to sound waves. The measurement profiles of these two aspects are presented quantitatively to provide an overview of students' achievements in technology-based physics learning.

There are still many challenges related to accelerating the mastery of physics concepts through technology. One of the main obstacles is students' low computational thinking skills, which prevent them from effectively utilizing technologies such as Scratch programming to understand physical phenomena. The need for an evaluation instrument that can uncover both computational thinking skills and physics concept mastery has become increasingly urgent. The Scratch-based Physics Computational Test can be an alternative solution for teachers to enhance physics learning strategies using computational technology approaches.

Analysis of Potential and Problems

Based on the needs analysis, the main potential of developing the Physics Computational Test lies in the scarcity of evaluation instruments that integrate computational thinking skills with physics content. Additionally, the advancements of the Fourth Industrial Revolution demand that every individual possess computational thinking skills, albeit at varying levels depending on their field of study or profession. The current educational context is primarily oriented toward multi-competency, where school graduates are expected to have diverse skills to compete in the workforce.

Data Collection

The data used in this research were obtained through literature studies, discussions with expert practitioners, and direct observations of the need for physics learning in schools. The literature reviewed included textbooks, journals, scientific articles, and information accessed via the Internet. Based on the data collection results, the main components that need to be developed in the Physics Computational Test include: (1) Test Relevance: The physics content must be related to real-life scenarios so that students' analyses are relevant to their experiences; (2) Test Rationality: The test must be able to uncover each component of computational thinking with sound logic that can be interpreted by students. (3) Test Consistency: The test should focus on revealing aspects of computational thinking skills and mastery of physics concepts to minimize bias.

Product Design

The Physics Computational Test instrument was designed based on the analysis of potential problems and information sources that had been collected. The test consists of multiple-choice questions with 21 items. Each question includes several objective items designed to measure computational thinking skills and mastery of physics concepts simultaneously. The Physics Computational Test is specifically used for learning sound wave material, integrating Scratch programming.

Using the Scratch platform in the Physics Computational Test aims to uncover students' computational thinking abilities based on their mastery of computational physics concepts. Scratch programming activities, which are closely related to mathematical content, serve as an ideal medium for developing students' computational thinking skills through the analysis of physical phenomena. For example, students are tasked with creating a sound wave simulation using Scratch, which requires an understanding of relevant mathematical equations, such as wave propagation speed, frequency, and the Doppler effect.

Design Validation and Revision

After the initial product was developed, the next step was to conduct content validation by validators who were experts in their respective fields. The validators were responsible for reviewing the test instrument based on three main criteria: (a) Material Aspect: The alignment between the test items and the testing objectives, as well as the characteristics of the test population; (b) Construct Aspect: The accuracy of the information conveyed in each test item; (c) Language Aspect: The clarity of words, phrases, or diagrams used in each item. Feedback from the validators was then used to revise and refine the test instrument to ensure its validity and appropriateness for measuring the intended skills and knowledge.

Table 3. Expert Validation Results

Validator	Content (%)	Construct (%)	Language (%)	Mean (%)
Validator 1	84	88	89	87.00
Validator 2	90	89	89	89.33
Validator 3	89	85	85	86.33
Mean (%)	87.67	87.33	87.67	87.55
Criteria	Very Feasible	Feasible	Very Feasible	Very Feasible

Based on Table 3, the material feasibility questionnaire results, 87.55% was obtained, indicating that the test instrument meets the criteria for being deemed suitable for use. The detailed validation results from the three validators are presented in Table 3. Based on feedback from the validators, several revisions were made to improve the quality of the test instrument, such as refining the wording of some questions to make them clearer and more aligned with the context of computational physics learning.

Trial Results

The Scratch-based Physics Computational Test instrument was piloted on 99 SMA Negeri 3 Semarang high school students. Before the trial, students were given instructional sessions on wave material guided by the researchers and school facilitators using the Scratch platform. This activity ensured that students understood the physics concepts being tested and were familiar with the Scratch programming environment. The trial results generated data on the characteristics of the test instrument and an overview of the students' computational thinking abilities.

Characteristics of the Test Instrument

The aspects of computational thinking abilities that were the focus of measurement include Decomposition, Pattern Recognition, Abstraction, Redefine Problems, Algorithmic Design, Strategic Decision Making, and Data Representation. These aspects reflect the core elements of computational thinking that are relevant to the context of physics learning. The characteristics of the test instrument are described through average scores, standard deviations, discrimination indices, and item difficulty levels. The reliability of the test was calculated based on the trial's results involving 99 students. The test instrument consists of 20 items, and the reliability analysis yielded a Cronbach's Alpha value of 0.781, which falls into the high category. More detailed data is presented in Table 4.

Table 4. Characteristics of the PICT Test from Trial Results

Item	Mean	Std. Deviation	Discrimination Index	Difficulty Level
1	0.68	0.490	0.63	0.65 b)
2	0.61	0.490	0.52	0.54 b)
3	0.69	0.452	0.56	0.52 b)
4	0.68	0.477	0.66	0.53 b)
5	0.69	0.481	0.53	0.66 b)
6	0.53	0.503	0.72	0.42 b)
7	0.68	0.477	0.55	0.44 b)
8	0.68	0.471	0.76	0.34 b)
9	0.65	0.481	0.66	0.71 a)
10	0.62	0.490	0.63	0.65 b)
11	0.69	0.490	0.79	0.65 b)
12	0.74	0.444	0.55	0.41 b)
13	0.71	0.459	0.66	0.28 c)
14	0.72	0.452	0.78	0.26 c)
15	0.66	0.477	0.64	0.52 b)
16	0.65	0.481	0.67	0.51 b)
17	0.51	0.452	0.78	0.52 b)
18	0.65	0.503	0.68	0.61 b)
19	0.72	0.406	0.67	0.58 b)
20	0.51	0.451	0.65	0.25 a)
21	0.62	0.421	0.64	0.53 b)

a) Easy b) Medium c) Difficult

All test items demonstrated good characteristics based on the data analysis in Table 4. The discrimination indices of the items generally ranged from 0.50 to 0.80, with several items, such as numbers 6, 8, 11, 14, and 17, showing excellent discrimination. The difficulty levels of most items fell into the moderate category, although items 13, 14, and 20 were classified as difficult.

Student Computational Thinking Ability Profile

Programming activities serve as the core of analyzing students' computational thinking abilities. The programming process follows a workflow that can accommodate all aspects of computational thinking, such as Decomposition, Pattern Recognition, Abstraction, Redefine Problems, Algorithmic Design, Strategic Decision Making, and Data Representation. Integrating physics content into each activity aims to measure computational thinking skills and reveal students' understanding of physics concepts.

Based on Figure 1, the highest achievement percentage is found in the Decomposition aspect, which measures students' ability to break down complex problems into simpler parts. The lowest achievement percentage is observed in the Algorithmic Design aspect, which requires students to design logical steps to build simulations. The high achievement in the Decomposition aspect is due to students' ease in understanding the initial stages of programming, while the low achievement in the Algorithmic Design aspect is attributed to the challenges students face in constructing algorithms, which are still relatively new to them.

Discussion

The Physics Computational Test developed in this study integrates programming tasks using Scratch with core physics concepts related to wave phenomena. The instrument consists of multiple-choice items designed to evaluate various aspects of computational thinking within physics problem-solving. By embedding programming activities in the test, the instrument aims to assess not only conceptual understanding but also students' ability to apply computational thinking skills in a meaningful and authentic manner. The following section discusses the validation outcomes and psychometric properties that characterize the test instrument's effectiveness and suitability for high school students.

The validation process confirmed that the Physics Computational Test based on Scratch programming is feasible for student trials. Expert validation ensured the instrument's alignment with the research objectives and its capability to effectively assess both computational thinking skills and mastery of physics concepts related to wave phenomena. Each aspect of computational thinking was operationalized through Scratch programming tasks embedded in physics content. For instance, the **Algorithmic Design** aspect evaluates students' ability to create logical sequences for simulating wave behavior, while the

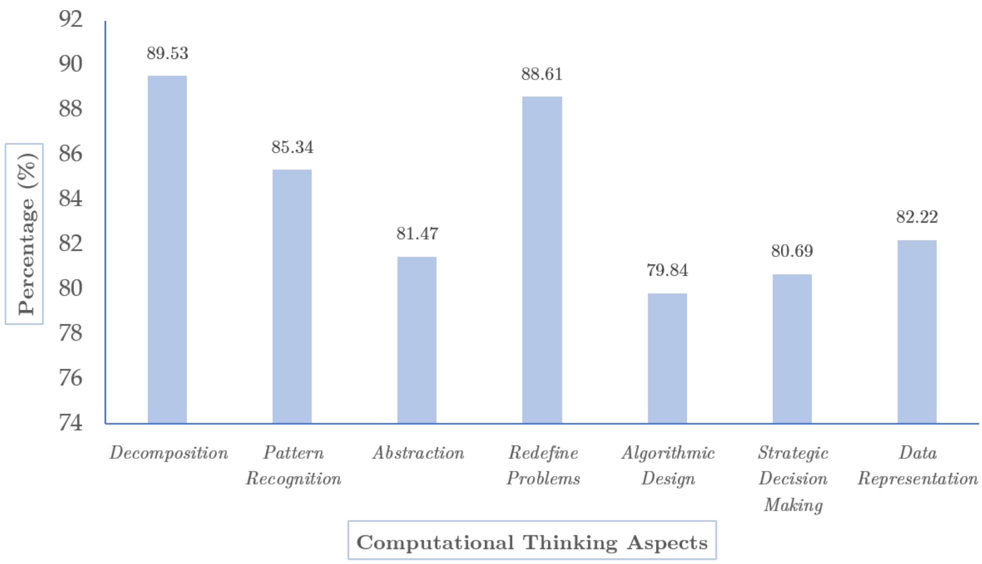

Figure 1. Achievement of Computational Thinking Skills for Each Aspect by Students

Abstraction aspect assesses their capacity to simplify complex physical phenomena into programmable mathematical models. Similarly, the **Data Representation** aspect reflects students' skill in visualizing physics data such as frequency, amplitude, or wavelength within the programming environment.

The test was intentionally designed to integrate physics concepts with computational approaches, supported by prior studies highlighting the synergistic relationship between physics education and programming (Bufasi et al., 2022; Lane et al., 2023). During development, subject matter experts rigorously reviewed each item's depth and accuracy, and interviews were conducted to confirm the instrument's relevance and appropriateness.

Although the test items are relatively straightforward and there is a potential risk of random guessing, psychometric analyses—including item difficulty and discrimination indices—demonstrate that the instrument effectively differentiates students' varying levels of computational thinking ability. This finding aligns with prior studies that emphasize the viability of programming-based assessments in accurately measuring higher-order cognitive skills in science education (Motjolopane, 2021; Ogegbo & Ramnarain, 2022). Thus, the Physics Computational Test shows promise as a reliable and valid tool for assessing computational thinking skills within the context of physics education. Furthermore, it offers valuable insight into students' conceptual understanding through technology-enhanced learning activities, consistent with research advocating for integrated STEM approaches that connect content knowledge and computational practices (Ezeamuzie & Leung, 2022; Kafai & Proctor, 2022).

Descriptively, students' mastery of physics concepts is evident in their performance on the test items. For instance, items targeting the Abstraction aspect require students to translate the concept of simple harmonic motion into a mathematical model suitable for implementation in Scratch, effectively bridging theoretical understanding and practical simulation. This approach resonates with findings from prior research demonstrating that computational tasks grounded in authentic scientific phenomena foster deeper conceptual learning (Odden & Zwickl, 2025; Shin et al., 2022).

Given the growing recognition of computational thinking as a fundamental skill in contemporary physics education, the development of a valid and contextually relevant assessment instrument remains critical. Overall, the analysis affirms that the Physics Computational Test is an effective measure of computational thinking skills embedded within physics content, specifically wave phenomena, for high school students. This study thereby contributes to the emerging body of literature supporting the integration of computational assessments in science curricula and provides a foundation for further research on the design and validation of similar instruments across various scientific domains.

Conclusion

The main product resulting from this research is the Scratch-based Physics Computational Test, an instrument designed to measure two critical aspects: students' computational thinking skills in the context of computational physics and their mastery of physics concepts related to wave phenomena. The test results are presented through detailed student achievement profiles, providing a comprehensive insight into how students utilize technology to understand and represent physical phenomena. As an alternative assessment tool, the Physics Computational Test enables teachers to identify and evaluate students' computational thinking abilities alongside their conceptual understanding of physics. Beyond its evaluative function, this instrument serves as a strategic reference for educators in designing more innovative and effective learning experiences that integrate technology and physics education. To further advance this line of research, future studies are recommended to explore the test's applicability across diverse student populations and extend its scope to other physics topics or science disciplines, thereby enhancing its generalizability and impact on STEM education.

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