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Curriculum and Student Needs Analysis in Special Relativity Learning:

A Preliminary Study for Developing Flipbook-Based Interactive Modules

Dewi Hikmah Marisda*
Physics Education, Faculty of Teacher Training and Education,
Muhammadiyah University of Makassar,
Jl. Sultan Alauddin No. 259, Makassar, 90221, Indonesia
[**Corresponding author*]

Ana Dhiqfaini Sultan
Physics Education, Faculty of Teacher Training and Education,
Muhammadiyah University of Makassar,
Jl. Sultan Alauddin No. 259, Makassar, 90221, Indonesia

Yusri Handayani
Physics Education, Faculty of Teacher Training and Education,
Muhammadiyah University of Makassar,
Jl. Sultan Alauddin No. 259, Makassar, 90221, Indonesia

Ma'ruf
Physics Education, Faculty of Teacher Training and Education,
Muhammadiyah University of Makassar,
Jl. Sultan Alauddin No. 259, Makassar, 90221, Indonesia

Putri
Physics Education, Faculty of Teacher Training and Education,
Muhammadiyah University of Makassar,
Jl. Sultan Alauddin No. 259, Makassar, 90221, Indonesia

Linda Sekar Utami
Physics Education, Muhammadiyah University of Mataram,
Jl. KH. Ahmad Dahlan No.1 Mataram, 83115, Indonesia

Abstract

Special relativity is a fundamental yet abstract topic in modern physics learning, which often causes difficulties for prospective physics teacher students. This study aims to analyze learning needs as a basis for developing interactive flipbook-based learning media on special relativity. The study was conducted at the defined stage in the 4D development model, which includes curriculum analysis, initial-final conditions, and student characteristics. The method used is descriptive qualitative, with data collection techniques through curriculum document reviews, questionnaires, and interviews with lecturers and students from two Physics Education Study Programs at Muhammadiyah Universities in Indonesia. The study showed a gap between learning outcomes and teaching methods that were still conventional and did not support concept visualization. As many as 67% of students had difficulty understanding the concept of special relativity, especially on the subtopics of time dilation and length contraction. Most students have visual and kinesthetic learning styles and want interactive and visual-based learning media. These findings indicate that the development of flipbook-based intermodal learning is needed to answer the needs of learning that is more contextual, visual, and in accordance with the learning profile of students in the digital era.

Keywords
Curriculum analysis, Interactive modules, Learning styles, Needs analysis, Special relativity

INTRODUCTION

The special theory of relativity developed by Albert Einstein is one of the main foundations of modern physics. Concepts such as time dilation, length contraction, and relativity of simultaneity offer a new perspective on space and time, fundamentally different from classical physics (Alstein et al., 2021; Voronov & Gerashchenko, 2018). The special theory of relativity requires students to understand very abstract concepts, such as time dilation and length contraction, which cannot be observed directly in everyday life (Marisda et al., 2025; Tene et al., 2024). Levrini and Fantini (2013) stated that the complexity of modern physics theories, especially relativity, often creates conceptual confusion that hinders the learning process (Levrini & Fantini, 2013). Despite its important position in the physics education curriculum, the abstract and difficult-to-visualize nature of this theory often becomes an obstacle for students in understanding and applying it in its entirety (Marisda et al., 2024; Podolak & Plattsburgh, 2013). Therefore, learning this topic requires a pedagogical approach allowing student (Mulhayatiah et al., 2022; Saehana et al., 2018).

Various studies have shown that many students have difficulty understanding the theory of relativity due to limitations in the learning approaches used, which tend to rely on verbal explanations and textbook texts without visual support or simulations (Candido et al., 2022; Rianti et al., 2020). Initial data from the Physics Education Study Program at a Muhammadiyah University in South Sulawesi showed that around 67% of students had difficulty understanding special relativity material in Modern Physics lectures (Marisda et al., 2023). This condition impacts low learning outcomes and students' cognitive engagement. The current physics education curriculum aims to achieve 21st-century competencies, emphasizing critical thinking skills, problem-solving, and mastery of technology. However, research by Baihaqi et al. (2022) shows that the implementation of this curriculum has not been fully supported by adaptive learning media, especially in the context of complex materials such as thermodynamics and relativity (Baihaqi et al., 2022).

On the other hand, the characteristics of students as learning subjects also need to be considered (van Seters et al., 2012). The characteristics of students at two Muhammadiyah universities in Indonesia, precisely in the provinces of South Sulawesi and West Nusa Tenggara, especially learning styles and cognitive backgrounds, greatly affect the effectiveness of learning. Rutten et al. (2012) stated that interactive and visual learning media can significantly improve the understanding of complex physics concepts, especially for students with a tendency towards visual and kinesthetic learning styles (Rutten et al., 2012). In this context, it is important to analyze the needs of students so that the media developed is truly adaptive to their learning characteristics (Vesin et al., 2018).

This gap indicates the need for a more innovative and adaptive learning approach to student needs. One solution offered is the development of an interactive flipbook-based module that is able to present material visually, dynamically, and easily accessible (Bisri et al., 2023; Mahendri et al., 2023). Digital flipbooks have been recognized as one of the effective media in supporting independent and interactive learning. Research by Yuyun et al. (2022) shows that using flipbook-based physics e-modules improves student learning outcomes and increases their motivation and involvement in the learning process (Yuyun et al., 2022). Flipbooks allow the integration of visuals, animations, and interactivity that bridge the understanding between theoretical and applied concepts in modern physics (Khaerunnisa et al., 2023). However, before developing the media, a comprehensive needs analysis is needed, especially at the define stage of the 4D development model (Thiagarajan et al., 1976), including curriculum analysis, initial-final conditions, and student characteristics. The 4D instructional development model emphasizes the importance of the define stage as the initial step to formulate learning needs comprehensively before the product is developed. In development research, the accuracy of conducting needs analysis greatly determines the relevance and effectiveness of the learning product being developed (Govindasamy et al., 2024).

This article aims to present the results of the needs analysis as a basis for developing an interactive flipbook-based module on special relativity. The main focus of this research includes (1) analysis of the Modern Physics course curriculum, (2) analysis of the initial-final conditions related to the teaching materials used, and (3) analysis of student characteristics and needs. The results of this analysis are expected to be a strong foundation in designing learning modules in accordance with the demands of the curriculum and student profiles in the 21st-century learning era.

METHODS

Types and Design of Research

This research is part of the research and development (Research and Development) which refers to the 4D development model (Define, Design, Develop, Disseminate) proposed by Thiagarajan, Semmel, and Semmel. However, this article specifically focuses on the initial stage, namely the Define stage, which aims to identify and analyze learning needs as a basis for developing interactive learning media based on flipbooks on the topic of special relativity.

Location and Subject of Research

The research was conducted in the Physics Education Study Program at two Muhammadiyah Universities in Indonesia, namely in the Provinces of South Sulawesi and West Nusa Tenggara in the 2023/2024 Academic Year. The research subjects consisted of: (1) Lecturers teaching Modern Physics courses, as informants in the analysis of the curriculum and teaching materials; (2) 40 students currently teaching Modern Physics courses, as respondents for the initial-final analysis and student characteristics.

Data Collection Techniques and Instruments

Data collection in this study was carried out through several complementary techniques and instruments. First, a curriculum document analysis was conducted by reviewing various official documents such as Graduate Learning Outcomes, Course Learning Outcomes, and Semester Learning Plans in Modern Physics Courses. This analysis aims to determine the extent to which the achievement of curriculum objectives is supported by the learning media used. Second, an initial-final analysis questionnaire was used, which was given to students to gather information about the actual condition of the available learning media and the level of difficulty they experienced in understanding the concept of special relativity. Third, a student characteristics questionnaire was distributed to identify the dominant learning style, motivation level, and student learning needs directly related to the relevant material. Data from these three instruments provides a strong basis for compiling a profile of student needs and the direction of relevant learning media development.

Before being used in data collection, all research instruments have been validated by four experts in the field of physics education and instructional development. Validation was carried out using Aiken's V method, with a scale assessment range of 1 to 5, where the number 5 indicates high suitability. The validation results showed that all instruments had met the criteria for content eligibility and relevance to the measurement objectives, so they were suitable for use in this study. The validation results were analyzed using Aiken's V method, which measures the validity level based on expert input.

After being assessed by experts, the researcher then calculates the results of the validator's assessment using the following Aiken Validation formula:

$$V = \frac{(\sum S)}{(N(c-1))}, \text{ where } s = r\text{-}l_0 \qquad (1)$$

information:

r = rater rating

l_0= low category assessor rating

c = highest category

N = number of respondents (Aiken, 1980)

Furthermore, to determine the feasibility of the product, the researcher refers to the Aiken table. For assessment with 4 assessors, and using a scale of 1-5, the instrument is said to be valid if it has an Aiken V value ≥ 0.88. Based on the analysis results, revisions were made to address the weaknesses identified in the validation. Thus, the validation process not only ensures the feasibility of the product, but also improves its quality to meet pedagogical standards (Yusoff, 2019). The average value of the validity measurement of the research instrument is Vcount ≥ 0.88. Therefore, the instrument is declared valid for use in research.

Data Analysis Techniques

The data in this study were analyzed descriptively qualitatively. Qualitative descriptive is an approach in research that aims to describe in depth and comprehensively a particular phenomenon, event, or condition based on non-numerical data, such as interviews, observations, or documents (Heinrich, 2024). Curriculum analysis is carried out by examining the suitability between the competencies targeted in official learning documents, such as Study Program Learning Outcomes and Course Learning Outcomes, with the types of learning media available and used in lectures. Meanwhile, data obtained from the initial-final questionnaires and student characteristics questionnaires were analyzed using descriptive statistics in the form of percentages, in order to provide an overview of student profiles, dominant learning styles, and the challenges they face in understanding special relativity material. All results from the three data sources are then synthesized to compile a comprehensive profile of student needs, which will be the basis for developing appropriate, relevant, and responsive teaching materials to the needs of modern physics learning.

RESULTS AND DISCUSSION

This section presents the results of the define stage in the flipbook-based intermodal development process for special relativity material. This stage is an important foundation in the 4D development model, which functions to identify learning needs comprehensively before the product design and development process is carried out. The analysis carried out includes three main aspects, namely: (1) analysis of the Modern Physics course curriculum, to see the suitability between learning outcomes and the teaching media used; (2) analysis of initial and final conditions, which describe the actual learning situation and the challenges faced by students; and (3) analysis of student characteristics, which aims to understand learning styles, motivation levels, and learning media preferences. The three results of this analysis are presented systematically and used as a basis for formulating the direction of appropriate and contextual teaching media development in accordance with student needs and the demands of the 21st Century Physics education curriculum.

Analysis of Modern Physics Course Curriculum

As an initial step, an analysis of the curriculum documents was conducted to obtain a more structured picture of the relationship between course learning outcomes and the teaching methods and media used in Modern Physics lectures (Tomczyk, 2024; Yalçin & Sadik, 2024). This analysis includes a review of the Semester Learning Plan, graduate learning outcomes, and the learning strategies and media applied. The purpose of this analysis is to identify potential gaps between curriculum demands and actual learning practices, as well as to formulate the need for the development of more contextual and relevant teaching media (Nalbantoğlu & Bümen, 2024). The results of the analysis are presented in Table 1 below;

Table 1 Gap Analysis between Course Learning Outcomes and Conventional Teaching Methods

Aspects	Curriculum Study Results	Actual Condition of Teaching Methods and Materials	Indication of Gaps	Implications/ Needs
Learning objectives	Students are able to explain the principle of special relativity and apply it in solving physical problems.	Learning is done through lectures and discussions, without simulations or interactive visual media.	Not all students can understand abstract concepts verbally.	There is a need for media that supports interactive visualization and modeling of physical concepts.
Learning strategies	Emphasizes the development of critical thinking and conceptual understanding through independent and collaborative exploration.	Dominantly based on textbooks and lecturer notes; does not involve technology-based activities	Learning does not fully activate students' cognitive engagement	An intermodal-based approach is needed that allows for active exploration.
Instructional Media	The curriculum supports the use of digital media to support technological literacy and strengthen conceptual understanding.	Conventional printed modules are still the only teaching materials available.	The media used does not reflect the integration of technology in learning	There is a need to develop digital flipbooks that support illustration, animation, and interactivity.
Curriculum Relevance	Aligning modern physics learning with the demands of the 21st century, including critical thinking and problem solving skills.	There is no media that can facilitate the development of 21st century skills effectively.	Teaching media is not contextual to curriculum needs and student characteristics	There is a need for intermodal development that encourages the integration of content, technology, and higher-order thinking approaches.

The results of the analysis of the Modern Physics course curriculum show a gap between the course's learning outcomes and the teaching methods that have been applied so far. Based on the Semester Learning Plan document, one of the learning outcomes of the course states that students are expected to be able to "explain the principles of special relativity and apply them in solving physical problems". However, the learning approach used in lectures is still dominated by lectures and text-based assignments, with the main teaching materials as printed modules without adequate visualization or simulation support. This is an obstacle for students in understanding abstract concepts such as time dilation and length contraction, which essentially require the support of visual and dynamic media (Buzzell et al., 2024; Zollman, 2016).
This condition reflects the mismatch between the learning strategies and the 21st-century competency-based curriculum demands. The current physics education curriculum emphasizes mastery of concepts and the development of critical thinking skills, problem-solving, and the use of technology in the learning process. In line with this, learning media are needed that are able to present materials in an interactive and interesting format, and can be accessed flexibly by students (Bao & Koenig, 2019; Henriksen et al., 2014; Morales, 2017; Žák & Kolář, 2023). One relevant alternative is the development of intermodal (interactive modern physics modules) based on flipbooks, which allow integration between text, animation, illustrations, and simple simulations in one digital platform (Bisri et al., 2023; Lilis et al., 2019). Thus, this media not only answers the needs of students pedagogically, but is also in line with the characteristics of 21st-century digital learning.

Analysis of Initial-Final Conditions of the Teaching Materials Used
Initial and final condition analysis was conducted to determine the actual situation of learning Modern Physics courses, especially on the topic of special relativity, before intermodal development was carried out. Data were obtained through a questionnaire distributed to students who were taking the Modern Physics course. Summary data from the initial and final condition questionnaire results that show a general picture of the limitations of teaching materials and student challenges in learning the topic of special relativity are presented in Table 2 below;

Table 2 Summary of Initial and Final Condition Questionnaire Results

Rated aspect	Initial Conditions (Before Intervention)	Final Condition (Current Observation)
Availability of digital media	Not available	Not yet available
Visualization of abstract concepts	Very minimal	Still not enough
Student involvement in learning	Low	Currently
Use of simulation or animation	Not used	Rarely used
Flexibility of access to materials	Limited to face-to-face classes	Not yet flexible
Suitability of media to face-to-face topics	Less relevant	Does not support visualization yet

Table 2 explains the results of the initial and final condition questionnaire, which shows that the learning modules used are still print-based, arranged narratively, and not equipped with visual illustrations, simulations, or interactive activities. The lecturer delivers the material in one direction, and learning generally relies on conventional lectures and discussions. In addition to the questionnaire, the initial and final condition analysis was also obtained from short interview data with several students. The interview data were then summarized and synthesized, presented in Table 3 below;

Table 3 Synthesis of Qualitative Findings

Theme	Description of Findings	Representative Quotes
Limitations of conventional learning media	Teaching media in the form of printed modules are not equipped with illustrations, animations, or simulations.	‘We only got printed modules, no in-depth simulations or visual examples.’
Cognitive Difficulties in Understanding Concepts	Students have difficulty visualizing concepts such as time dilation and length contraction.	‘It’s hard to imagine how time could possibly slow down just because of speed.’
Expectations for interactive and visual media	Students expect visual-based media such as animations, simulations, and interactive e-books.	‘I think it’s really helpful. You can study anytime and the material is more alive with the animations.”
Impact on learning outcomes and self-confidence	Learning difficulties cause low self-confidence and less than optimal learning outcomes.	‘I became less confident during the exam because I didn’t really understand the concept.’

Short interviews were conducted with several Modern Physics students to explore their experiences, perceptions, and obstacles in studying special relativity material. The purpose of the interviews was to obtain more contextual information regarding the suitability of the teaching media to the students' learning needs, especially in understanding abstract concepts (Qu & Dumay, 2011). The results of the interviews were analyzed qualitatively and categorized into several main themes based on the similarity of the answer patterns. The four main themes successfully identified from the interview results are described as follows.

Theme 1: Limitations of Conventional Learning Media

All interviewed students stated that the learning media used in the Modern Physics course, especially on special relativity, are still conventional and lack visualization. They stated that printed modules cannot facilitate understanding of abstract concepts such as time dilation and length contraction. One student said, *“We only get printed modules; there are no in-depth simulations or visual examples.”* This indicates the need for learning media that are not only informative but also visually communicative.

Theme 2: Cognitive Difficulties in Understanding Abstract Concepts

Students have difficulty in imagining and interpreting the concept of relativity in concrete terms, especially because the nature of matter cannot be observed directly in everyday life. Most of them mentioned the subtopics of time dilation and length contraction as the most confusing part. Statements such as *“It is hard to imagine how time can go slower just because of speed,”* reflect the real cognitive challenges in learning modern physics without adequate visual media support.

Theme 3: Expectations for Interactive and Visual Media

All respondents showed high enthusiasm for the possibility of developing digital-based learning media. They explicitly mentioned illustrations, simulations, animations, videos, and interactive e-books as the forms of media they expected. One student said, *“I think it’s very helpful. I can learn anytime, and the material is more alive with animation.”* This confirms that the development of flipbook-based intermodal has great potential to improve understanding of concepts independently and flexibly.

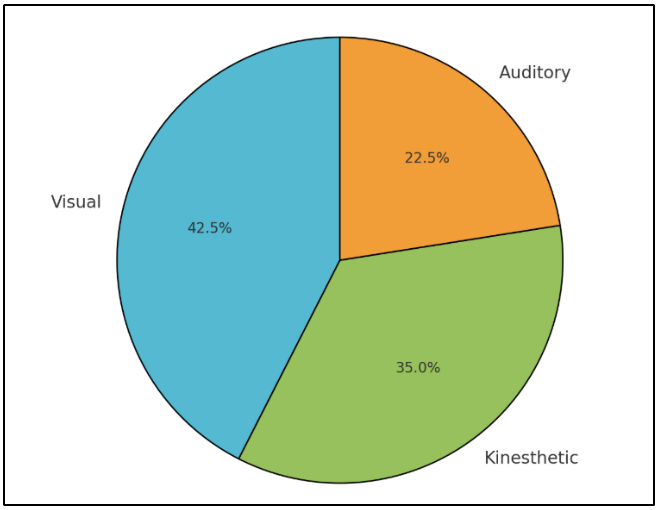
Theme 4: Impact on Learning Outcomes and Self-Confidence

Difficulty understanding the material also impacts students' self-confidence and learning outcomes. Some admitted they were not confident when facing exams because they did not understand the concept. One student said, "I became less confident during the exam because I did not really understand the concept." This shows that the gap in teaching media impacts students' cognitive and affective aspects.

Analysis of Student Characteristics and Needs

Analysis of student characteristics was conducted to identify learning profiles that can be the basis for designing relevant and effective intermodals (Kotkas et al., 2016; Perdanasari et al., 2021; van Seters et al., 2012). The questionnaire results showed that as many as 67% of students had difficulty understanding the concept of special relativity, especially in abstract subtopics such as time dilation and length contraction. Students expressed that they had difficulty visualizing these concepts, and felt that verbal or text explanations alone were not enough to build deep conceptual understanding (Hamzah et al., 2022; Marisda et al., 2023; Sartika & Humairah, 2018).

In addition, the questionnaire data also revealed that most students have visual (42.5%) and kinesthetic (35%) learning styles, while the rest have auditory tendencies. This shows that most students need teaching media that can present information through images, graphs, illustrations, and interactive activities that allow independent exploration of concepts. Visual learning styles require stimuli in the form of visual representations of complex information, while kinesthetic learning styles rely on active and practice-based or simulation-based learning experiences (Cassidy, 2004; Chaudhry et al., 2020; Chetty et al., 2019). A compares these learning style tendencies can be seen in Graph 1 below.



Graph 1 Distribution of Student Learning Styles on Special Relativity Material

These findings indicate an urgent need for a learning model based on interactivity and visualization. Learning media such as interactive digital modules based on flipbooks have the potential to answer these needs, because they allow integration between text, moving images, simple simulations, and easy-to-use navigation features (Maynastiti et al., 2020; Susanti et al., 2020). The presence of this kind of media is expected to not only improve students' conceptual understanding of difficult material (Hasni et al., 2025; Simaremare et al., 2022), but also to increase learning motivation and active involvement in the modern physics learning process (Adawiyah et al., 2021; B & Purwatiningsih, 2023; Sari & Khaidir, 2023).

CONCLUSION

Based on the analysis results at the define stage in the 4D development model, three main conclusions were obtained that are relevant to the design of teaching media appropriate to the context and needs of physics education students. *First*, the curriculum analysis shows a gap between the learning outcomes of the course and the conventional teaching methods that are still dominantly used. The Modern Physics Curriculum emphasizes mastery of concepts and developing high-level thinking skills, but the lecture method and printed modules with minimal visualization have not supported these achievements optimally. The need for teaching media that support interactivity and visualization is very important to bridge the demands of the curriculum with the reality of classroom learning.

Second, the initial and final condition analysis results revealed that students still rely on conventional teaching materials without the support of digital media, simulations, or interactive activities. Most students have difficulty understanding abstract concepts such as time dilation and length contraction. The findings of in-depth interviews strengthen the questionnaire data and show that limited media contribute to low student self-confidence and learning outcomes. This strengthens the urgency of providing media that can visualize concepts in a concrete and easy-to-understand manner.

Third, the student characteristics analysis shows that most have visual and kinesthetic learning styles. They need media to present learning content in a dynamic visual form and provide exploration space through simulations or direct interaction. Interactive flipbooks are considered capable of answering this need because they allow the integration of text, animation, and simulation in one flexible and easily accessible digital format. Overall, the results of this study provide a strong foundation for the next stage in developing flipbook-based intermodals that are contextual, adaptive, and in accordance with the demands of modern physics learning in the digital era. In the future, it is hoped that the products developed will not only be curricularly relevant, but will also be able to improve conceptual understanding, motivation, and active involvement of students in the learning process.

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DECLARATION OF CONFLICT

The authors declare that no conflict of interest could influence the results or interpretation of this study.

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