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The Effectiveness of Special Relativity Student Worksheet Assisted by The Pythagorean Theorem in Physics Learning

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Abstract

In the 21st-century education era, integrating innovative learning media is essential to develop mathematical thinking skills and improve overall student learning outcomes, especially when addressing highly abstract physics topics such as Einstein's special theory of relativity. This research aims to implement a specifically designed Student Worksheet (SW) assisted by the Pythagoras theorem to develop mathematical thinking indicators, enhance student learning performance, and evaluate student responses toward the media. The research employed a pre-experimental method with a one-group pretest-posttest design conducted at SMAN Mumbulsari during the 2024/2025 academic year. Using convenience sampling, 72 eleventh-grade students from two physics elective classes were selected as research subjects. Data collection was carried out using validated pretest-posttest essay questions, Student Worksheets focused on four key mathematical thinking elements: specializing, generalizing, conjecturing, and convincing, and response questionnaires based on a Likert scale. Data analysis utilized the Normalized Gain (N-gain) score to measure the improvement in learning outcomes and descriptive statistics to determine the percentage of student responses. The results indicated that students' mathematical thinking skills fell into the good to very good range across all indicators. Furthermore, learning outcomes showed an average N-gain of 0.57, placing the improvement in the moderate category, complemented by a positive student response rate of 68.20%. These findings demonstrate that the Pythagoras-assisted SW effectively improves learning performance in physics. This research provides significant practical benefits as an innovative instructional alternative for physics teachers, simplifying complex, abstract concepts through a geometric approach, thereby helping students overcome mathematical barriers and fostering a deeper understanding of physics.

Keywords: effectiveness, mathematical ability, student worksheet, special relativity of the Pythagorean theorem.

INTRODUCTION

Education is one of the efforts to educate individuals and develop their potential (Leoni, 2025). According to Amaliyah and Rahmat (2021), the educational process can be influenced by environmental factors, allowing the learning process to be adjusted to the nature and essence of the environment and enabling students' potential to develop in line with today's demands. Collaborative problem-solving is essential for developing 21st-century learning skills. These skills include critical thinking, creativity, collaboration, and communication, commonly known as the 4Cs (Tang, Vezzani, & Eriksson, 2020). Problem-solving ability shapes a person's thinking in determining solutions to the problems at hand. Fostering one's way of thinking can be done by strengthening science literacy and thinking skills, which ideally begin to be instilled in school. Heleni, Saragih, and Suanto (2025) argue that teachers, as educators, should actively design learning scenarios that maximize student participation and engagement.

Student Worksheets (SW) have become a crucial necessity in schools as a systematic medium for sharpening students' mathematical thinking skills, while simultaneously serving as a transformative instrument to shift the paradigm away from teacher-oriented learning (Resmi, 2020). This conventional learning pattern has been identified as a contributing factor to students' low mathematical competence; thus, an intervention through specifically designed worksheets is required to emphasize the active learning process (Herlina & Ihsan, 2020). By focusing on student activities, the utilization of these worksheets serves as an effective strategy for optimizing the mathematical thinking framework.

Low learning outcomes are often driven by student boredom during the educational process, necessitating innovative learning tools that enhance learners' skills (Suwarno, Wahidin, & Nur, 2020). A primary effective instrument is the Student Worksheet (SW), which serves as a systematic guide for students to conduct investigations and engage in problem-solving activities (Melawati, Evendi, Halim, Yusrizal, & Elisa, 2022). The implementation of worksheets designed to assist students in independent concept discovery has been shown to enhance understanding and improve cognitive and skill-based learning outcomes significantly.

One effective teaching material is the Student Worksheet (SW). Student Worksheet encourages students to be active, think critically, and learn independently through structured, problem-based activities (Dalimunthe & Anas, 2024). Research (Sari, Isnaeni, & Ellianawati, 2024) found that a student worksheet based on Problem-Based Learning (PBL) can improve critical thinking skills. This Student Worksheet has proven to be more feasible, practical, and effective than conventional teaching materials used by teachers in improving students' critical thinking. In general, physics is a branch of science that positions mathematics as its language (Fitria et al., 2023). Mastery of mathematical concepts is important in the physics learning process, enabling students to understand phenomena conceptually and practically (Siswanto & Andriyani, 2025). However, many students still experience difficulties in learning physics due to low mathematical thinking skills (Wadjdi, 2025). The results of the PISA study show that the mathematical thinking ability score of Indonesian students has decreased year by year: 386 in 2015, 379 in 2018, and 366 in 2022, all of which are below the international average in each year.

The low level of students' mathematical achievement is significantly driven by math anxiety, stemming from fear of failure, task difficulty, time pressure, and concerns about poor grading (Szczygieł & Pieronkiewicz, 2022). The persistence of low mathematical problem-solving skills across various educational levels—from primary to higher education—indicates a critical need for targeted instructional strategies to improve learning outcomes and mathematical literacy (Juandi & Tamur, 2021).

According to Ibrahim, Tunku, and Isa (2023), students' mathematical thinking skills exhibit significant deviations, as evidenced by the high accumulation of wrong and incomplete responses across all Mathematical Thinking (MT) elements. In the *Specializing* element, the lack of accuracy is reflected in error rates of up to 64% and incomplete responses reaching 54% on specific items. This condition becomes more critical in the *Generalizing* and *Conjecturing* elements, where incomplete responses dominate by up to 62%, while incorrect conjectures surge drastically to 98%. The lowest performance is observed in the *Convincing* element, where the failure to provide mathematical justification (*wrong*) reaches 98%, and the failure to provide complete arguments reaches 66%. These findings emphasize that students' cognitive processes in mathematical investigations are not yet well-facilitated, necessitating instruments such as Student Worksheets (SW) to provide systematic guidance in reducing these learning obstacles.

Student learning outcomes are key indicators of instructional success. Research shows that media-based learning enhances contextual understanding (Yusnidar, Fuldiaratman, & Chaw, 2024; Dwiyanti & Setyasto, 2025). while evaluation-based materials significantly boost critical and mathematical thinking (Fahruddin, Kurniawanti, Nurgiansah, & Gularso, 2025). Ultimately, integrating innovative media with evaluation-driven materials is vital for optimizing students' conceptual grasp and higher-order thinking skills.

To train students' problem-solving abilities, students can be strengthened in their mathematical thinking skills (Anggo, Suhar, & Yana, 2025). Students are required not only to understand concepts theoretically but also to apply them using mathematical language (Turan, Rotsaert, & De Smedt, 2025). Mathematical thinking skills based on research by Delima, Kusumah, and Fatimah (2021) have 4 indicators, including a) Specializing, b) Generalizing, c) Conjecturing, and d) Convincing. Then, according to the research by Yenilmez, Ozcan, Batu, & Mart (2022), indicators of mathematical ability are a) Generalizing, b) Specialization, c) Logical thinking, and d) Using Symbols, e) Conjecturing.

According to Albert Einstein's theory of relativity, the theory is divided into two theories: general relativity and special relativity (Noer & Dayana, 2021). General relativity concerns the curvature of spacetime. Meanwhile, the theory of special relativity discusses space and time as perceived by observers moving at a constant speed. In the theory of special relativity, Einstein discusses time dilation, length contraction, time, and relativistic energy (Lumbangaol, Purba, Misbah, Siahaan, & Siagian, 2023).

Einstein's special theory of relativity is a complex topic in physics. Students often struggle to grasp the theory both conceptually and mathematically, resulting in consistently low learning outcomes (Ayu, Ardianti, Wanabuliandari, 2021). Generally, special relativity equations are solved using Lorentz transformations. However, including the gamma factor in these transformations complicates calculations and makes problem-solving time-consuming.

$$\gamma = \frac{1}{\sqrt{1-\left(\frac{v}{c}\right)^2}} > 1 \quad (1)$$

Mathematically, the equations for time dilation, relativistic mass, relativistic energy, and length contraction are as follows.

$$\Delta t = \gamma\, \Delta t_0 \quad (2)$$

$$m = \gamma m_0 \quad (3)$$

$$E = \gamma E_0 \quad (4)$$

$$L = \frac{L_0}{\gamma} \quad (5)$$

The study conducted by (2019) revealed that a Pythagorean-theorem-based approach simplifies the calculation of spacetime intervals, time dilation, and length contraction, while providing clearer, more accessible mathematical representations for students. The Pythagorean theorem is a fundamental concept in geometry that applies to right triangles and states that the square of the hypotenuse equals the sum of the squares of the two perpendicular sides (Nirmalasari, Sampoerno, & Makmuri, 2021). The geometric representation of these relativistic variables is illustrated in Figure 1.

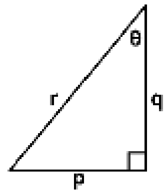


Figure 1. Triangle with Pythagoras

Based on the concept of trigonometry, the relationship between the three sides can be written as follows.

$$\frac{p^2}{r^2} + \frac{q^2}{r^2} = 1 \quad (6)$$

By applying Equation (6) to Einstein's special relativity, the standard formulas can be reformulated into Pythagorean-like equations. This transformation allows physical variables such as time, mass, and energy to be mapped onto the geometric properties of a triangle. Specifically, the relationship for time dilation is visually represented in Figure 2, where the sides are labeled according to their respective relativistic components.

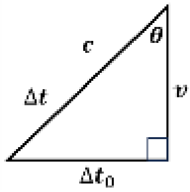


Figure 2. Right Triangle Representing Time Dilation

The resulting equations for various relativistic phenomena are presented below.

$$\frac{\Delta t_0^2}{\Delta t^2} + \frac{v^2}{c^2} = 1 \quad (7)$$

Mass change:

$$\frac{m_0^2}{m^2}+\frac{v^2}{c^2}=1 \quad (8)$$

Relativistic energy:

$$\frac{E_0^2}{E^2}+\frac{v^2}{c^2}=1 \quad (9)$$

Long contractions:

$$\frac{L^2}{L_0^2}+\frac{v^2}{c^2}=1 \quad (10)$$

These equations can facilitate conceptual understanding and problem-solving in the special theory of relativity. Furthermore, research by Supriadi, Puspitasari, Dani, Rahmawati, and Mukarromah (2022) demonstrates that applying the Pythagorean method to relativistic energy topics can effectively improve student learning outcomes. Based on these considerations, this study aims to develop a Student Worksheet (LKPD) integrating the Pythagorean theorem into the material on Einstein's special relativity. The objective is to evaluate mathematical thinking skills, improve student learning outcomes, and determine student responses toward the effectiveness of this Pythagorean-based learning media.

METHODS

This pre-experimental study, employing a one-group pretest-posttest design, was conducted at SMAN Mumbulsari during the even semester of the 2024/2025 academic year. Due to the small number of students in the physics elective, convenience sampling was used to select 72 eleventh-grade students from two classes. Data collection targeted two primary variables: mathematical thinking skills and learning outcomes. Mathematical thinking was assessed through a Student Worksheet (SW) specifically designed to evaluate four elements: *Specializing, Generalizing, Conjecturing,* and *Convincing*. To assess learning outcomes, a pretest consisting of 4 validated essay questions was administered during the first session. In the second session, students completed the SW, which served as both an investigation guide and a posttest instrument. The effectiveness of the intervention was evaluated by analyzing the improvement from pretest to posttest using the N-gain score. The instruments, validators, and expertise used to refine this research are shown in Table 1.

Table 1. Validation of Research Instruments

No.	Instrument	Validator	Experience
1	Student Worksheet (SW/LKPD)	Academic expert & media expert	Theoretical physics specialist & learning media development specialist
2		Practitioner	Physics teacher (20 years' experience) & physics teacher (5 years' experience)

The design of this research is shown in Table 2.

Table 2. One Group, Pretest and Posttest Design

Group	Pre-Test	Treatment	Post-Test
Experiment	0_1	X	0_2

The research follows a structured design involving a pre-test (O_1), an experimental treatment, and a final assessment (1) represents the initial assessment given to students to measure their baseline skills. In contrast, (2), denotes the final assessment conducted to evaluate the improvement after the intervention. The treatment (X) consists of learning activities implemented through the application of the Pythagorean Theorem within the context of Einstein's Special Theory of Relativity. The data collected from these stages are then used to determine the effectiveness of the learning implementation.

The assessment in this study includes learning outcomes measured through pretest and posttest activities, as well as mathematical thinking skills assessed using the indicators of *specializing, generalizing, conjecturing,* and *convincing* (Delima, Kusuma, & Fatimah, 2021) through Student Worksheets. The scores for both variables are determined by comparing the obtained score to the maximum score as follows.

$$Score=\frac{Total\ correct\ score}{Total\ maximum\ score} \quad (11)$$

The assessment category of mathematical thinking ability indicators used in this study is shown in Table 3.

Table 3. Categories of Assessment of Indicators of Mathematical Thinking Ability

Value Range (%)	Categories
$85-100$	Excellent
$70-84$	Good
$55-69$	Enough
$40-54$	Less
<40	Very less

Source: (Scott, 2018)

Furthermore, before analyzing the improvement in learning outcomes, a normality test is first conducted to ensure that the pre-test and post-test data are normally distributed. The entire series of statistical tests, including the normality test and the Normalized Gain (N-Gain) calculation, are performed using SPSS software. The N-Gain test itself aims to determine the effectiveness of thin improving students' learning outcomes, which is calculated using the formula proposed by Hake (1999):

$$\langle g \rangle = \frac{\langle posttest\ score\rangle - \langle pretest\ score\rangle}{ideal\ score - \langle pretest\ score\rangle} \quad (12)$$

The effectiveness criteria for the Normalized Gain $\langle g \rangle$ test are shown in Table 4.

Table 4. Normalization Gain

Limitations	Categories
$\langle g \rangle$ < 0.3	Low
0.3 ≤ $\langle g \rangle$ ≤ 0.7	Medium
$\langle g \rangle$ > 0.7	Height

The researcher distributed a questionnaire to assess students' understanding of the application of Pythagoras theorem in the Special Theory of Relativity. The Likert-scale questionnaire includes five aspects: interest, motivation, satisfaction, and response (Supriadi et al., 2025). Criteria are used to measure students' understanding, effectiveness, and interest in learning. The score criteria for response results are as shown in Table 5.

Table 5. Response Score Criteria

Categories	Score
Strongly agree	5
Agree	4
Hesitation	3
Disagree	2
Strongly disagree	1

Source: (Sugiyono, 2016)

The participant response questionnaire data were converted to percentages using the equation below and grouped by the categories listed in Table 6.

$$Presentase = \frac{total\ score\ obtained}{highest\ score} \times 100\% \quad (13)$$

Table 6. Response Percentage Category

Presentation	Categories
$1\ \% < P\ \leq 20\%$	Very unpositive
$20\ \% < P\ \leq 40\%$	Less positive
$40\ \% < P\ \leq 60\%$	Quite positive
$60\ \% < P\ \leq 80\%$	Positive
$80\ \% < P\ \leq 100\%$	Very positive

Source : (Arikunto, 2010)

RESULTS AND DISCUSSION

This study implements student worksheet assisted by Pythagoras' theorem on Einstein's special relativity material. This student worksheet is designed to help students understand modern physics concepts using basic geometry, thereby facilitating learning. Before being used in the learning process, this student worksheet underwent validation by experts and practitioners to assess its feasibility for implementation in high schools. The expert validation results achieved a score of 95.4% and were categorized as feasible for testing without revision. Meanwhile, based on the practitioner validation results, it obtained a score of 92.2%. This validation is an important basis before the worksheet is implemented in the learning process.

The student worksheet, supported by the Pythagorean theorem in Einstein's special relativity material, is used to train and assess mathematical thinking skills and to improve student learning outcomes. The syntax or stages in the student worksheet make it easier for students to connect mathematical concepts with concepts in Einstein's special relativity material. Each step in the student worksheet requires students to analyze, develop a solution strategy, and evaluate the results of the calculations. This reflects their mathematical thinking skills. Using simple mathematical methods to solve Einstein's special relativity equations can improve student learning outcomes. To provide a clearer overview of the integration of geometric concepts in this physics material, the following visual illustration shows the student worksheet that uses the Pythagorean theorem to derive the relativistic equations.

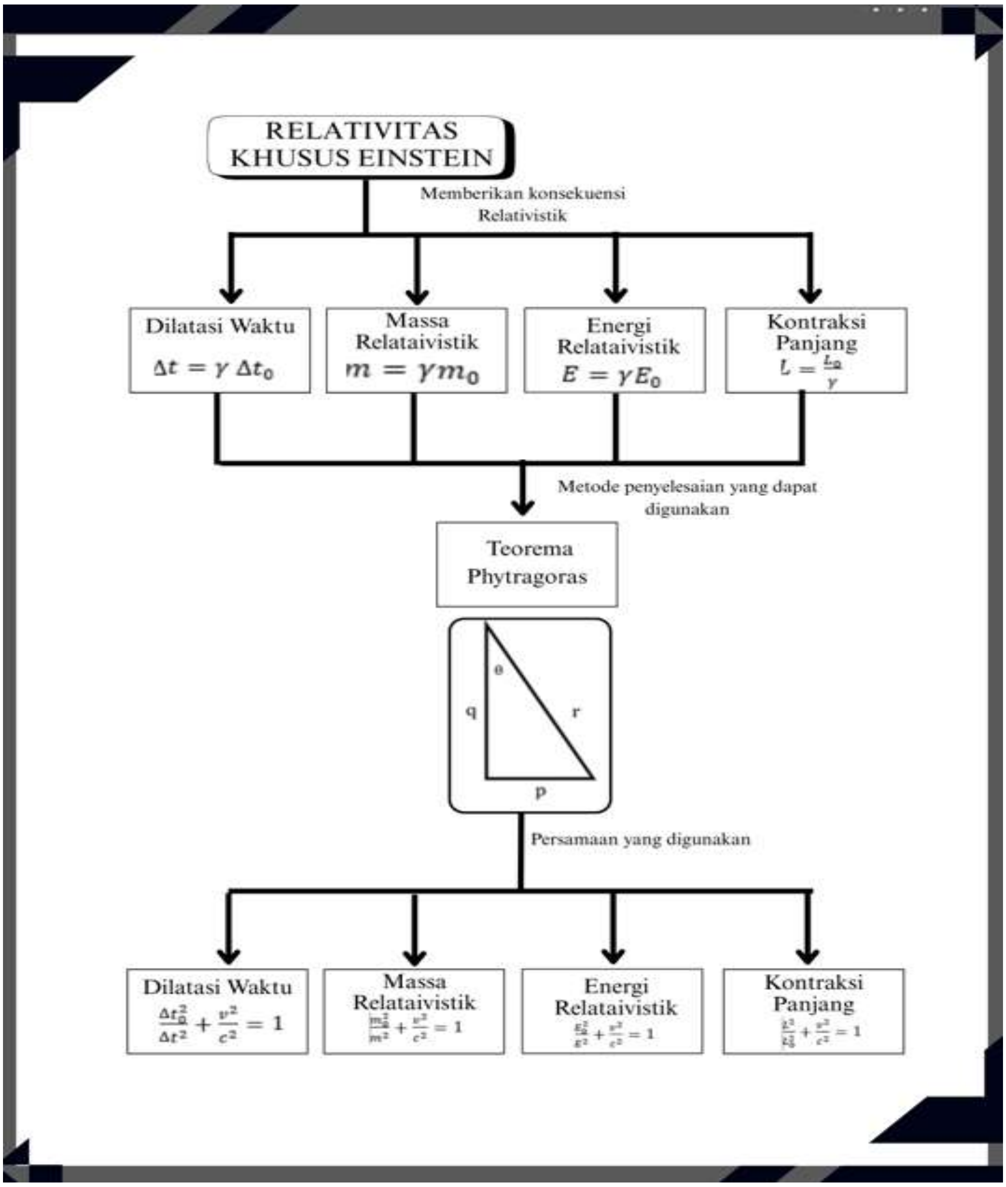


Figure 3. Concept Map

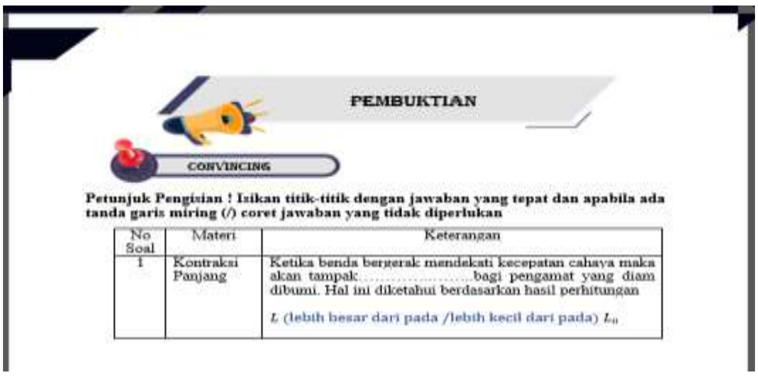
Based on Figure 3, a concept map of Einstein's special relativity is presented to help students understand the basic concepts of special relativity, such as reference frames, the equivalence of physical laws, the speed of light, time dilation, and length contraction, as well as the systematic and hierarchical relationships between these concepts. Through this concept map, students are guided not only to memorize formulas but also to relate the principles of physics underlying special relativity to relevant physical phenomena. The presentation of the concept map is expected to facilitate students' development of a comprehensive conceptual understanding, improve their analytical skills, and reduce misconceptions that often arise in special relativity material.

Figure 4. Conjecturing Indicator in the Student Worksheet

Figure 4 shows the Conjecturing indicator, which measures students' ability to formulate initial conjectures from a stimulus. In this section, students are directed to work on three problem-identification questions based on the stimulus. Through these activities, students are required to observe relevant information, recognize emerging problems, and formulate initial assumptions or hypotheses logically before proceeding to further solutions. Thus, this section serves as a measure of the Conjecturing indicator, as it assesses students' ability to construct initial assumptions that are rational and based on their understanding of the concepts.

Figure 5. Specializing in the Student Worksheet

Figure 5 shows the Specializing indicator, which measures students' ability to apply the general concepts and principles of special relativity to solve specific problems. In this section, students are given special relativity problems and are directed to solve them using conventional special relativity methods and the Pythagorean theorem. Using two different solution approaches, students are required to apply concepts appropriately, select appropriate solution strategies, and demonstrate mathematical accuracy in the context of the given problems.



Petunjuk Pengisian ! Isikan titik-titik dengan jawaban yang tepat dan apabila ada tanda garis miring (/) coret jawaban yang tidak diperlukan

No Soal	Materi	Keterangan
1	Kontraksi Panjang	Ketika benda bergerak mendekati kecepatan cahaya maka akan tampak……………bagi pengamat yang diam dibumi. Hal ini diketahui berdasarkan hasil perhitungan L (lebih besar dari pada /lebih kecil dari pada) L_0

Figure 6. Convincing Indicator in the Student Workshee

Figure 6 shows the Convincing indicator, which measures students' ability to justify and reinforce their results. In this section, students are asked to complete a proof table that shows the relationships between variables and the previously obtained results. Through this activity, students are required to identify patterns, relate relevant results, and formulate them logically and systematically.

Figure 7. Generalizing Indicator in the Student Worksheet

Figure 7 shows the Generalizing indicator, which measures students' ability to draw general conclusions from patterns, relationships, or results from specific cases. In this section, students are asked to write conclusions accurately and logically based on the previously carried out problem-solving process. This activity requires students to relate the calculation results to the relevant concepts of special relativity and to draw conclusions that are consistent with the physical and mathematical principles used.

A. Mathematical Thinking Ability

Based on the research, students' mathematical thinking skills were assessed after completing a Student Worksheet that used the Pythagorean theorem to support material on Einstein's special relativity. The following equation determines the maximum value of each indicator.

$$Score_{max} = \sum(S_i \times I_{max} \times N) \quad (14)$$

Where S_i represents the obtained score for each indicator, I_{max} maximum indicator score, and N number of students. Accordingly, the maximum score for the Conjecturing indicator was 864, followed by 4.320 for the Specializing indicator, 576 for the Generalizing indicator, and 876 for the Generalizing indicator. The following research results present the total accumulation obtained by all students.

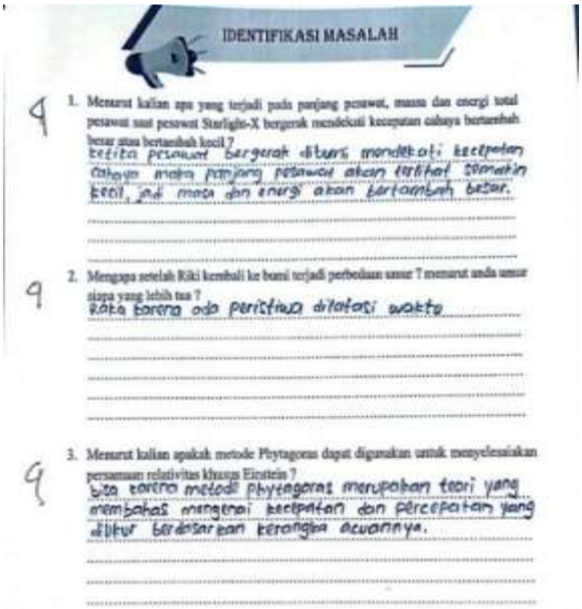
Table 7. Maximum Score of the Indicator of Mathematical Thinking

No.	Indicator	Maximum Score
1	Conjecturing	789
2	Specialize	3.352
3	Convincing	438
4	Generalization	802

The analysis of the data presented in Table 7 represents the accumulation of mathematical thinking scores, obtained by multiplying the number of students by the maximum score for each mathematical thinking indicator. This maximum score accumulation serves as a benchmark for assessing students' overall mathematical thinking skills. By comparing the student's score with the maximum score, the level of mastery of the student's mathematical thinking can be determined.

Conjecturing

The first indicator is *conjecturing; students are considered to meet the conjecturing indicators well if they* can articulate the information obtained. Then, students can make guesses based on their knowledge and logical reasoning (Sylvenny, Zulkardi, & Ratu, 2025). The ability to make conjectures in problem-solving can be observed in the students' responses shown in Figure 8.



IDENTIFIKASI MASALAH

9 1. Menurut kalian apa yang terjadi pada panjang pesawat, massa dan energi total pesawat saat pesawat Starlight-X bergerak mendekati kecepatan cahaya bertambah besar atau bertambah kecil ?

ketika pesawat bergerak dibuat mendekati kecepatan cahaya maka panjang pesawat akan terlihat semakin kecil, jadi massa dan energi akan bertambah besar.

9 2. Mengapa setelah Riki kembali ke bumi terjadi perbedaan umur ? menurut anda umur siapa yang lebih tua ?

Roka karena ada peristiwa dilatasi waktu

9 3. Menurut kalian apakah metode Phytagoras dapat digunakan untuk menyelesaikan persamaan relativitas khusus Einstein ?

bisa karena metode Phytagoras merupakan teori yang membahas mengenai kecepatan dan percepatan yang diukur berdasarkan kerangka acuannya.

Figure 8. Students' Answers to Suspected Indicators

Based on the images of the answers, students can estimate changes in length, mass, and energy as objects approach the speed of light. Students can also make conjectures about the causes of age differences and express opinions about the Pythagoras method for special relativity, based on a case given in this Student Worksheet. The students' mathematical thinking ability on *the conjecturing* indicator is shown in Figure 9.

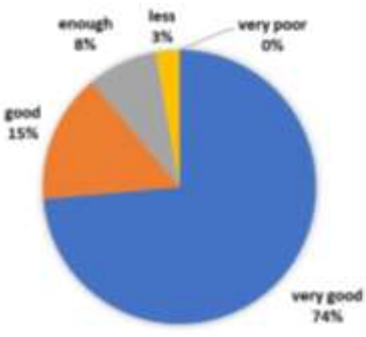


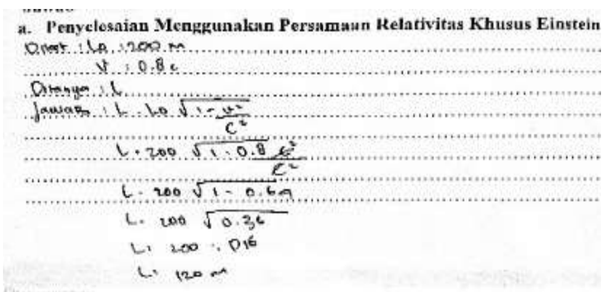
Figure 9. Percentage on Indicators Conjecturing

Based on the drawing, the percentages of students' mathematical thinking ability shown in Figure 9 indicate that students' conjecturing ability is generally well developed. This suggests that students were able to generate assumptions and draw logical conclusions from the information provided. The highest percentage is in the very good category. This shows that using the researcher-developed Student Worksheet can improve students' conjecturing abilities. This is because in the Student Worksheet, the material is presented in stages: beginning with understanding the initial concept, then introducing Pythagoras' equations in general, and finally providing problem stimuli to encourage students to associate initial knowledge with new concepts. So that students can make reasonable guesses, including relating Pythagorean equations to solving Einstein's special relativity problem.

As stated by Ibrahim, Ahmad, and Isa (2023), research indicates that students who demonstrate strong hypothesis-making abilities also exhibit high levels of problem-solving skills and creativity. In this case, hypothesis-making not only facilitates the formation of potential solutions but also promotes a deeper understanding of mathematical concepts and encourages flexible thinking.

Specializing

The second indicator in mathematical thinking is specialization. Students are considered to meet the specialization indicator if they can solve problems in various ways to obtain correct results (Siswanto & Andriyani, 2025). Students can solve Einstein's special relativity problems in two ways: using general equations or using Pythagoras' theorem. In Figure 10 below, students' answers are presented using the general special relativity equation method, namely equation (5).



a. Penyelesaian Menggunakan Persamaan Relativitas Khusus Einstein

Diket : $L_0 = 200$ m

$v = 0.8c$

Ditanya : L

Jawab : $L = L_0 \sqrt{1 - \frac{v^2}{c^2}}$

$L = 200 \sqrt{1 - 0.8 \frac{c^2}{c^2}}$

$L = 200 \sqrt{1 - 0.64}$

$L = 200 \sqrt{0.36}$

$L = 200 \cdot 0.6$

$L = 120$ m

Figure 10. Students' Answers Using Special Relativity Equations in General

Meanwhile, the results of the students' answers using Pythagoras' theorem, as stated in equation (10), are presented in the following figure.

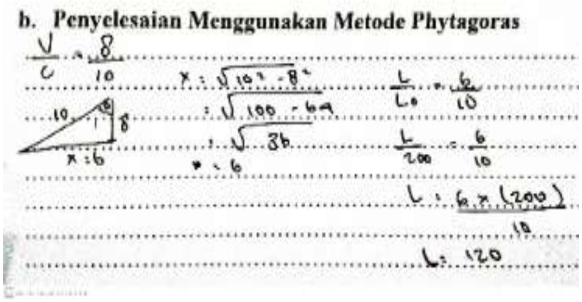


Figure 11. Students' Answers with the Pythagorean Theorem Approach

Figure 11 above shows that students can solve special relativity problems in two ways: using Einstein's special relativity equation in general, and using the Pythagorean theorem method. With these two approaches, students can prove the same results. The results show students' ability to think logically and analytically, which is one of the mathematical thinking skills in the Specializing indicator. The mathematical thinking ability of students on the specialization indicator is shown in the following figure.

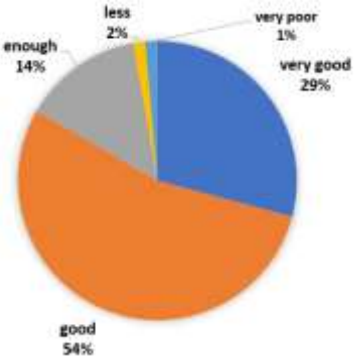


Figure 12. Percentage on the Specializing Indicator

Based on the drawing results shown in Figure 12, students' mathematical thinking ability in the specialization indicator is generally well developed. Most students demonstrated good to very good performance in identifying problem characteristics and applying appropriate mathematical representations by using the Pythagorean theorem method in special relativity material.

The ability to think mathematically in the indicator specializing in the category is good, as the average student can solve problems using two methods well. However, some students have difficulty solving problems using the usual equation method, as shown in the following figure. According to Isa (2023), specialized ability is key in mathematical thinking. Specialized abilities help students deepen their understanding of mathematical concepts and promote adaptability in problem-solving.

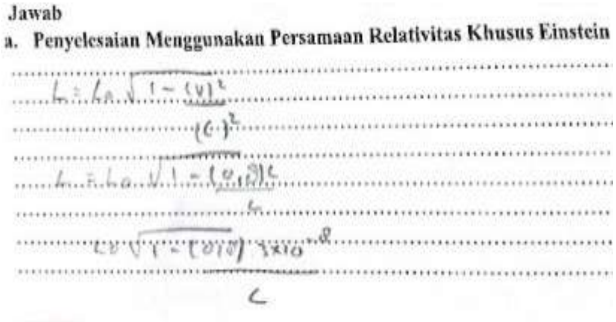


Figure 13. Students' Answers Using Special Relativity Equations in General

In Figure 13 above, it can be seen that students have difficulty calculating the square root of the speed of light (c), so they do not continue the calculation. The following are the students' answers using the Pythagoras method.

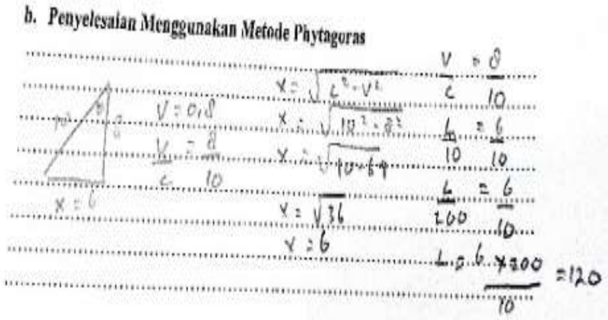


Figure 14. Students' Answers with the Pythagorean Theorem Approach

Based on Figure 14 above, when students use the Pythagorean theorem to solve Einstein's special relativity problem, they can get the correct answer. This is consistent with the research by Supriadi et al. (2019), which found that the Pythagoras theorem method makes it easier to solve Einstein's special relativity problem.

The Student Worksheet developed by the researcher can be used as a medium for training and measuring specialization skills, as it includes stages of data collection that encourage students to apply the Pythagorean equation to the Einstein special relativity equation. From this stage, students obtained the equation for a right-angled triangle to find time dilation, contraction length, relativistic mass, and relativistic energy. Next, they were instructed to solve special relativity problems using the collected data. Then, students can solve the problem using two different methods and obtain the same final result. This is one of the advantages of the Student Worksheet, designed by researchers through these stages to improve students' mathematical thinking.

Convincing

The third indicator in mathematical thinking is convincing. Students are considered to meet the convention indicators if they can demonstrate physics concepts that are logically supported by calculations or mathematical proofs, thereby enabling the concepts to be correctly trusted (Zeynivandnezhad, Emilio, Yusof, & Ismail, 2025). The ability to convince students is evident in students' answers in Figure 15.

Petunjuk Pengisian ! Isikan titik-titik dengan jawaban yang tepat dan apabila ada tanda garis miring (/) coret jawaban yang tidak diperlukan

No Soal	Materi	Keterangan
1	Kontraksi Panjang	Ketika benda bergerak mendekati kecepatan cahaya maka akan tampak lebih pendek bagi pengamat yang diam dibumi. Hal ini diketahui berdasarkan hasil perhitungan L (~~lebih besar dari pada~~ /lebih kecil dari pada) L_0

Figure 15. Answers for Students in the Convincing Stage

Based on the drawings, students can demonstrate concepts in Einstein's special relativity material using the results of the calculations. Thus, students can understand the concept of special relativity based on the results of its mathematical proofs. The mathematical thinking ability of students is shown in the following Figure 16 as a convincing indicator.

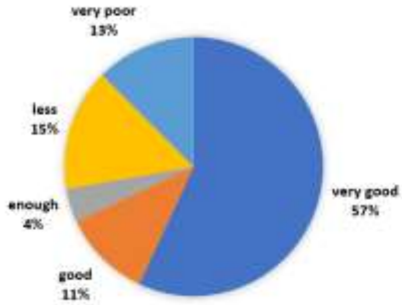


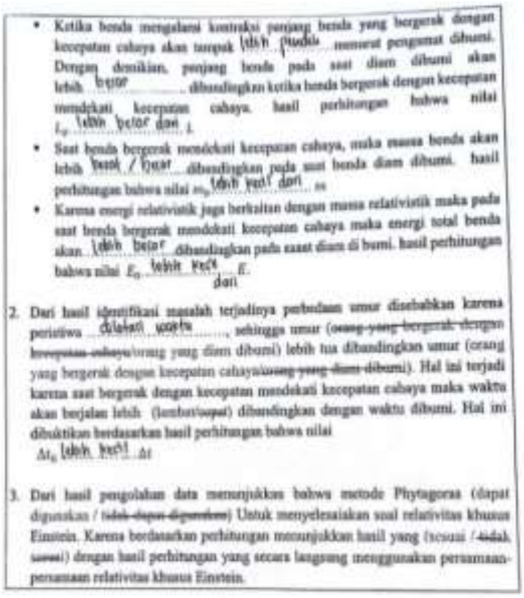
Figure 16. Percentage of Convincing Indicator

Based on the drawing results, students' mathematical thinking ability in the conjecturing indicator is generally well developed. Most students demonstrated strong performance, with the highest achievement observed in the very good category. This shows that students can provide logical proofs to support the concept of special relativity, based on mathematical calculations assisted by the Pythagorean theorem they have learned. This success indicates that using the Student Worksheet, supported by the Pythagorean theorem, to solve special relativity problems can make it easier for students to understand the concepts and increase their ability to think mathematically.

As research by Ibrahim, Ahmad, and Isa (2023) suggests, students who are strong in demonstrating strong abilities also demonstrate higher logical reasoning and critical thinking skills, so the use of the Student Worksheet has been proven effective in bridging their ability to articulate their reasons and provide strong justifications to prove the truth of mathematical statements.

Generalizing

The fourth indicator in mathematical thinking is generalizing. Generalizing indicators is the ability of students to draw logical conclusions from analyzed data or evidence. Students are considered to meet the generalizing indicator if they can use the results of the data collection process to draw conclusions that answer the problem based on their guesses (Nurmaliza, Ariawan, Dahlia, Nufus, & Nurdin, 2022). Students' generalization ability is evident in their answers, as shown in Figure 17.



- Ketika benda mengalami kontraksi panjang benda yang bergerak dengan kecepatan cahaya akan tampak lebih pendek menurut pengamat dibumi. Dengan demikian, panjang benda pada saat diam dibumi akan lebih besar dibandingkan ketika benda bergerak dengan kecepatan mendekati kecepatan cahaya. hasil perhitungan bahwa nilai L_0 lebih besar dari L.
- Saat benda bergerak mendekati kecepatan cahaya, maka massa benda akan lebih besar / berat dibandingkan pada saat benda diam dibumi. hasil perhitungan bahwa nilai m_0 lebih kecil dari m
- Karena energi relativistik juga berkaitan dengan massa relativistik maka pada saat benda bergerak mendekati kecepatan cahaya maka energi total benda akan lebih besar dibandingkan pada saat diam di bumi. hasil perhitungan bahwa nilai E_0 lebih kecil dari E.

2. Dari hasil identifikasi masalah terjadinya perbedaan umur disebabkan karena peristiwa dilatasi waktu, sehingga umur (~~orang yang bergerak dengan kecepatan cahaya~~/orang yang diam dibumi) lebih tua dibandingkan umur (orang yang bergerak dengan kecepatan cahaya/~~orang yang diam dibumi~~). Hal ini terjadi karena saat bergerak dengan kecepatan mendekati kecepatan cahaya maka waktu akan berjalan lebih (lambat/~~cepat~~) dibandingkan dengan waktu dibumi. Hal ini dibuktikan berdasarkan hasil perhitungan bahwa nilai Δt_0 lebih kecil Δt

3. Dari hasil pengolahan data menunjukkan bahwa metode Phytagoras (dapat digunakan / ~~tidak dapat digunakan~~) Untuk menyelesaikan soal relativitas khusus Einstein. Karena berdasarkan perhitungan menunjukkan hasil yang (sesuai / ~~tidak sesuai~~) dengan hasil perhitungan yang secara langsung menggunakan persamaan-persamaan relativitas khusus Einstein.

Figure 17. Students' Answers to Generalizing Indicators

The drawings show that students can conclude from data obtained through mathematical calculations assisted by the Pythagorean theorem in Einstein's special relativity problem. With this method, students can not only solve special relativity problems but also draw conclusions about Einstein's special relativity and test the conjectures they made beforehand. The mathematical thinking ability of students in generalizing indicators is shown in Figure 18.

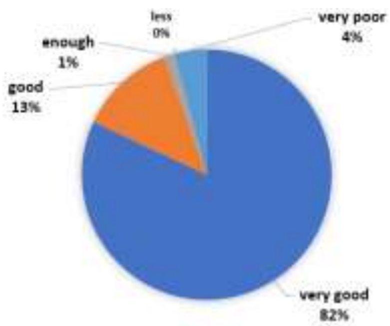


Figure 18. Percentages on Generalizing Indicators

Based on the results in Figure 18, students' mathematical thinking ability in the generalizing indicator is very well developed. The highest percentage is in the very good category. This shows that students can generalize concepts from the results of the majority calculation. In addition, students can conclude the problem-solving process using the Pythagorean method. It can be concluded that the stages in the Student Worksheet, assisted by the Pythagoras theorem, are effective in encouraging students to find patterns and to reach independent, logical conclusions.

The results of the above study show that the Student Worksheet, assisted by Pythagoras, can be used to train students' mathematical thinking skills. This aligns with research by Yuslia, Mariana, and Ekawati (2025), which found that an Ethnomathematics-based Student Worksheet can improve mathematical skills. Then, research by Bai, Zhang, and Wang (2025) also states that Multimodal Large Language Models (MLLM) can be used, with the help of mathematical theorems such as the Pythagorean theorem, to analyze learners' mathematical reasoning. The research (Isran, Susanta, Rahimah, & Syafri, 2025) states that applying mathematical theory to physics problems can train critical, logical, and analytical thinking skills, which is one of the mathematical thinking skills.

In a study by Amit, Ibrahim, Ahmad, and Isa (2023), students who demonstrated strong generalization abilities also showed higher levels of abstraction, indicating an understanding of underlying structures and relationships. This highlights the interaction between generalization and other cognitive processes involved in mathematical thinking. The ability to generalize allows individuals to identify underlying principles and apply them to solve new problems. Understanding the role of generalization in mathematical thinking provides insight into how individuals understand and apply mathematical concepts, thereby promoting deeper understanding and stronger problem-solving proficiency.

B. Learning Outcomes

The increase in physics learning outcomes in Einstein's special relativity material was measured using pretests and posttests. The pretest is conducted before learning using the Einstein relativity formula, while the posttest is conducted after implementing the Student Worksheet Pythagoras method on Einstein's special relativity material. Based on the research results, the average pretest, posttest, and N-gain values were obtained using SPSS, as shown in Figure 19.

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
NGain	.194	72	.000	.795	72	.000

Figure 19. Test of Normality Results

Recapitulation of test results on the implementation of the Student Worksheet (LKPD) based on the Pythagorean method on Einstein's Special Relativity material in learning. This trial was carried out as an initial effort to assess the extent to which applying the Student Worksheet can help students understand the concepts of special relativity more concretely, as well as to encourage improvements in learning outcomes through a more contextual approach. The following is a recapitulation of student learning outcome data in Table 8. Next

Table 8. Student Learning Outcome Data

Description	Value	
	Pretest	Posttest
Total number of students	72	72
Lowest grade	35.7	62
Highest score	92.8	98
Average score	59.9	83.2
Average N-gain	0.57	
Category	Medium	

Based on Table 8, students' learning outcomes show a noticeable improvement from pretest to posttest. This result is supported by the increase in the average score and the medium N-Gain category, indicating that the learning method was moderately effective in enhancing students' learning outcomes. outcomes of students in special relativity material after the implementation of the Student Worksheet. The Pythagoras method for Einstein's special relativity is included in the medium category. $0{,}3 \leq \langle g \rangle < 0{,}7$.

Through the achievement of mathematical thinking indicators, which include *conjecturing, specializing, convincing*, and *generalizing*. Students demonstrate excellent ability to make informed guesses, solve problems using various methods, prove concepts, and infer information from mathematical calculations. Strengthening mathematical thinking skills directly improves student learning outcomes, as evidenced by the increase in learning outcomes after implementing the Student Worksheet, which is included in the medium category. Thus, the Student Worksheet can train students' problem-solving skills by strengthening mathematical thinking and also significantly improve student learning outcomes. This research aligns with several previous studies, such as that conducted by Yamin, Napitupulu, and Harahap (2022), which found that a Student Worksheet based on a scientific approach can improve students' mathematical problem-solving ability, with an N-gain value of 0.41, which falls within the medium category. The research (Rézio, Andrade, & Teodoro, 2022) indicates that learning grounded in scientific approaches can enhance students' mathematical problem-solving skills through the application of Problem-Based Learning (PBL) in applied mathematics, which is effective in improving engineering students' problem-solving skills. PBL encourages collaboration, reflection, and discussion of concepts, all of which contribute to improved mathematical thinking skills. Furthermore, research by Palinussa, Dias, and Ngilawajan (2021) indicates that the Realistic Mathematics Education (RME) and PBL learning models significantly improve students' mathematical problem-solving skills, particularly when accounting for students' initial mathematical abilities.

The results of the study show that students' mathematical thinking skills are in the very good category, consistent with relatively good learning outcomes. This proves that the higher the student's mathematical thinking ability, the more optimal the achievement of learning outcomes. Strong mathematical ability encourages students to understand concepts, analyze problems, and develop systematic solution strategies, thereby directly impacting student learning outcomes. Research conducted by Ratnawati, Handayani, and

Wati (2020) supports this finding, showing that the learning model significantly improves students' mathematical critical thinking skills. In addition, research by Sappaile et al. (2024) shows that the development of mathematical thinking encourages student learning outcomes.

C. Response

Student responses were collected via a questionnaire after students were guided through the Student Worksheet on solving Einstein's Special Relativity using Pythagoras' Theorem. The analysis of response data for 5 indicators is presented in Table 9 below.

Table 9. Data from the Response Questionnaire

Indicator	Highest Average Likert Scale Percentage	Categories	Average/ Category
Interest	66%	Positive	
Motivation	71%	Positive	68.20% Positive
Inclination	70%	Positive	
Satisfaction	68%	Positive	
Response	66%	Positive	

Based on the above, it can be seen that the students' responses to the use of Pythagoras' Theorem in solving Einstein's Special Relativity material for 5 indicators had an average presentation of 68.20%, which falls within the positive category.

Indicators of Interest

The indicator of interest received a positive response from students, with a 66% response rate. This shows that students are interested, excited about learning, and happy to solve Einstein's special relativity problems using the Pythagoras method, and that they are interested in applying the Pythagoras method to other physics materials. This result supports the findings of Ate, Parno, and Munfaridah (2025), who reported that structured mathematical representations can reduce students' difficulties in abstract physics topics and lead to more positive learning responses. The average student responses are based on the four questions presented in the distributed interest indicators shown in Figure 20.

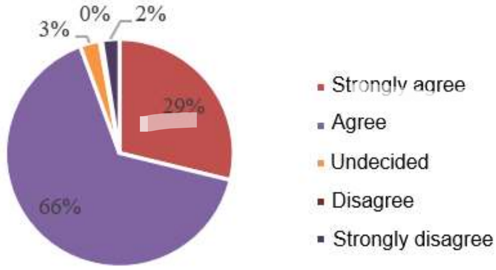


Figure 20. Percentage Chart of Interest Indicators

Motivation Indicators

The motivation indicator received a positive response from students, with a 71% response rate. This shows that students are motivated, excited, encouraged, and confident in working on Einstein's special relativity problems with the Pythagoras method. The positive motivational response observed in this study can be explained by students' confidence in their ability to solve problems. This is consistent with self-efficacy theory, which suggests that higher confidence enhances students' motivation and persistence in learning tasks (Voica, Singer, & Stan, 2020). The average student responses are based on the four questions presented in the motivation indicators shown in Figure 21.

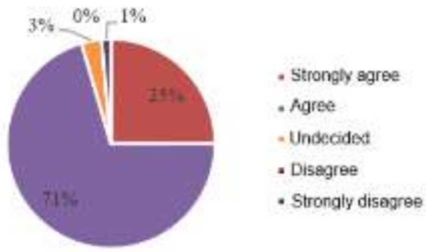


Figure 21. Percentage Chart of Motivation Indicators

Indicators of Inclination

The inclination indicator received a positive response from students, with a 70% response rate. This shows that students find it easier to solve Einstein's special relativity problems, are more diligent in doing assignments related to Einstein's special relativity, are diligent in learning about Einstein's special relativity, and have a deeper curiosity about Einstein's special relativity with the Pythagoras method. This finding is consistent with that of Nusantara, Febrianty, and Pasaribu (2025), who state that students' interest enhances cognitive engagement and facilitates problem-solving. The average student responses are based on the four questions presented in the distributed inclination indicators shown in Figure 22.

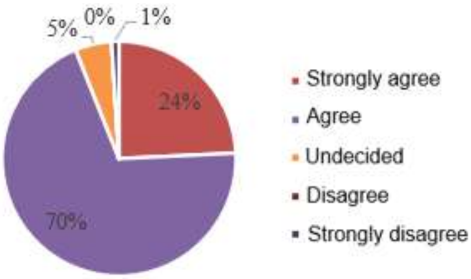


Figure 22. Percentage Chart of Inclination Indicators

Satisfaction Indicators

The satisfaction indicator received a positive response from students, with 68% of students responding positively. This shows that students have increased their insight in solving Einstein's special relativity problems, feel that the use of the Pythagoras method is in accordance with their needs, and feel that the use of the Pythagoras method makes them more exploratory in solving problems about relativity, and the use of the Pythagoras method is in accordance with my expectations in solving problems about Einstein's special relativity. Kobicheva, Tokareva, and Branova (2022) explain that students' satisfaction increases when they perceive improvement in their understanding and learning outcomes. The average student responses are based on the four questions presented in the satisfaction indicators shown in Figure 23.

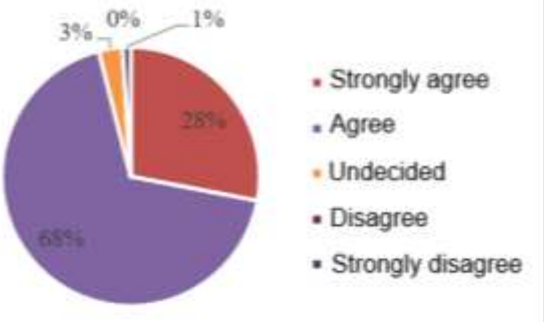


Figure 23. Percentage Chart of Satisfaction Indicators

Perception Indicators

The perception indicator received a positive response from students, with a 66% response rate. This shows that students find the Pythagorean method in Einstein's special relativity easy to understand, with clear stages of work; its use adds to his insights, improves his mathematical skills, and helps him work faster and more concisely on Einstein's special relativity problems, offering new alternative solutions. Costley, Gorbunova, Courtney, Chen, and Lange (2024) explain that clearly structured problem-solving procedures reduce cognitive load, making learning tasks easier to understand and execute. The average student responses are based on the four questions presented in the distributed response indicators shown in Figure 24.

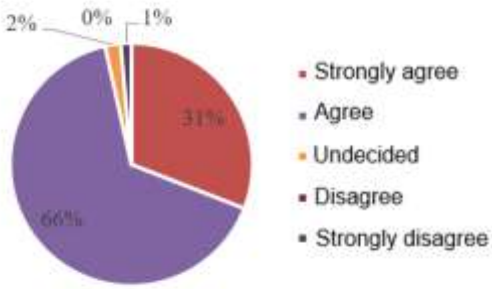


Figure 24. Percentage Chart of Response Indicators

Based on the study's results, the Student Worksheet Relativity, which specifically used the Pythagorean theorem in physics instruction, received an average student response of 68.20% in the positive category. Based on the research results, student responses, and the increase in physics learning outcomes, the data show that the average posttest score is higher than the average pretest score. Based on the N-Gain test results, the average score was 0.57, placing it in the medium category. The posttest score is higher than the pretest score. These results show that students' mathematical thinking skills have improved. This is in accordance with the opinion (2024). Based on the questionnaire results, an average of 73.6 was obtained, indicating a good category, so it can be concluded that the STEM-based e-Student Worksheet developed received a positive response from students. The response stated that the e-

Student Worksheet improved critical thinking skills, fostered a spirit of learning, and reduced boredom during the learning process. This is in accordance with the opinion of Daryanto et al. (2022), who found that their research on increasing students' learning motivation after using an interactive e-Student Worksheet shows that an innovative e-Student Worksheet can encourage increased learning motivation. This is due to the presence of various interactive features in the e-Student Worksheet, such as audio, video, animation, and other engaging symbols, which present learning materials in a more varied and engaging way, thereby encouraging more active student involvement in the learning process.

The results from the data above show that the Student Worksheet, which used the Pythagorean theorem in the context of Einstein's special relativity material, received a positive response from students. This indicates that the Student Worksheet makes it easier for students to understand the material based on mathematical concepts. The use of the Pythagorean theorem in the Student Worksheet can encourage students to practice mathematical thinking skills, which are important for improving student learning outcomes. The data show an increase in learning outcomes after using the Student Worksheet. The results of this study align with the research (Khaeriyah & Kana, 2025), which found that developing a realistic, mathematics-based Student Worksheet can improve critical thinking skills and elicit a positive response from students. The research by Supriadi et al. (2025) also found that the mathematical approach of Cramer's rule is effective in improving students' critical thinking skills and learning outcomes.

CONCLUSION

The implementation of Student Worksheets (LKPD) based on the Pythagorean Theorem in Special Relativity materials has proven effective in training students' mathematical thinking skills and enhancing physics learning outcomes. Quantitatively, the training of mathematical thinking reached significant scores across four indicators: conjecturing (789/864), specializing (3,352/4,320), convincing (438/576), and generalizing (802/876), demonstrating students' ability to connect concepts through logical conjectures and draw sound conclusions. This success is further evidenced by improvements in learning outcomes: the average pretest score rose from 59.9 to 83.2 on the posttest, yielding an average N-Gain of 0.57 (moderate). Qualitatively, the Student Worksheet received a positive response rate of 68.2%, indicators of interest (66%), motivation (71%), inclination (70%), satisfaction (68%), and Perception (66%). These data indicate that the Pythagorean method effectively simplifies abstract physics concepts, making it a highly recommended systematic and contextual learning tool for high school teachers.

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