Journal of Mathematics Instruction, Social Research and Opinion
Vol. 4, No. 3, September 2025, pp. 931 – 942, https://doi.org/10.58421/misro.v4i3.682
ISSN 2962-7842

Rasch Model Analysis of Spatial Visualization Test Items on the Pythagorean Theorem for Junior High School Students Using Ministep

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Article Info

Article history:

Received 2025-08-14
Revised 2025-09-01
Accepted 2025-09-28

Keywords:

Phytagoras theorem
Rasch Model
Spatial Visualization

ABSTRACT

The lack of valid and reliable test instruments to measure junior high students' spatial visualization skills, especially regarding the Pythagorean Theorem, prompted this study. The goal of this research is to assess the quality of spatial visualization test items related to the Pythagorean Theorem for junior high students. This study used a quantitative descriptive approach with Rasch Model analysis via Ministeps software. The developed instrument included 11 essay questions administered to 30 ninth-graders through purposive sampling. Results showed that 5 items were valid, while 6 needed revision. The instrument's reliability coefficient was 0.91 (high). Based on difficulty, there were 3 easy, 2 moderate, and 6 difficult items. This instrument meets Rasch Model standards and is suitable for measuring junior high students' spatial visualization abilities concerning the Pythagorean Theorem, serving as a reference for designing more accurate and representative math assessments..

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1. INTRODUCTION

Spatial visualization ability is a fundamental foundation in understanding mathematical concepts, particularly in the Pythagorean Theorem. This ability involves the skills of imagining, rotating, and manipulating two or three-dimensional objects mentally [1]. In mathematics learning, spatial visualization plays an essential role as it is closely related to cognitive processes in solving complex geometry problems [2]. However, the study by Cholilah [3] reported that junior high school students' spatial ability is still in the medium category, with spatial visualization ranked fourth compared to mental rotation and spatial orientation. This finding indicates the need to improve students' spatial visualization ability through more targeted teaching and assessment approaches. Therefore, it is important to develop measurement instruments that can more accurately capture students' spatial visualization skills as a foundation for effective instructional strategies.

Various studies have shown that technology-based media can be an effective solution to enhance spatial visualization ability. Sugiarni et al. [4] reported that GeoGebra-based visual media developed using the ADDIE design were highly valid (99.11%) and practical (83.26%) for learning the Pythagorean Theorem. Pauweni et al. (2022) also found that applying GeoGebra improved student learning outcomes from 64.91% to 81.83% and increased both teacher and student engagement. Aulia et al. [5] reinforced these findings by showing a significant improvement in students' spatial visualization, evidenced by an N-Gain score of 0.80. Meanwhile, Karomah et al. [6] and Sari et al. [7] emphasized that visual-based learning not only improves spatial understanding but also strengthens memory retention and spatial thinking speed. Although these findings highlight the effectiveness of learning media, reinforcement through valid assessment is still required so that teachers can objectively evaluate students' progress.

Nevertheless, instruments to measure spatial visualization ability at the junior high school level still face challenges of validity and reliability. Jumrah et al. [8] used the Rasch Model to develop HOTS-based instruments on solid geometry and found that this approach was effective in ensuring item quality. Thayaseelan et al. [9] also emphasized the importance of content and construct validity in spatial instruments, while Hidayat & Nurrohmah [10] demonstrated that Rasch analysis can identify misfitting items, making instruments more accurate. Lusiyana & Nurjanah [11] further added that a comprehensive analysis covering item difficulty, discrimination power, and measurement accuracy is crucial. This implies that without valid and reliable instruments, evaluations of students' spatial visualization ability will tend to be biased and less representative.

The Rasch Model is known for its excellence in producing objective measures that are free from sample dependency and able to map the distribution of students' abilities accurately [12]. Ambarwati & Maarif [13] demonstrated its effectiveness in developing numeracy literacy instruments with high reliability and balanced item difficulty distribution. Sudihartinih & Prabawanto [14] also affirmed that the Rasch Model is highly suitable for measuring item fit to students' abilities. International studies have also shown their success, such as Hizqiyah et al. [15] in measuring computational thinking skills and Jumini et al. [16] in developing technological literacy instruments. With these advantages, the Rasch Model provides a strong foundation for analyzing item quality while ensuring that instruments are fair to all learners [17], [18], [19], [20], [21].

A research gap emerges because most previous studies only focused on general spatial ability measurement or the development of geometry instruments in a broader sense, without specifically addressing spatial visualization ability in the Pythagorean Theorem validated through the Rasch Model. Nevertheless, this specific measurement is essential to provide an accurate picture of students' abilities and to serve as a foundation for developing appropriate learning strategies. Therefore, this study positions itself to fill the gap by developing a more focused and well-validated instrument.

Based on this background, this study aims to develop and analyze the quality of spatial visualization test items on the Pythagorean Theorem for junior high school students using the Rasch Model with Ministeps software. The study is expected to produce an instrument that is valid, reliable, and capable of mapping item difficulty levels as well as the distribution of students' abilities objectively. The results are expected to benefit teachers, researchers, and curriculum developers in designing formative and summative assessments that are fair, accurate, and adaptive to student characteristics. In addition, this study has the potential to provide practical contributions to the preparation of diagnostic instruments that can help schools improve the quality of mathematics learning, particularly in spatial visualization.

2. METHOD

This study employed a descriptive quantitative design aimed at developing and testing the quality of an instrument for measuring ninth-grade junior high school students' spatial visualization ability using the Rasch Measurement Model. The research was conducted at SMPN 2 Sumberjaya, Majalengka Regency, during the second semester of the 2025/2026 academic year. The focus was directed toward students who had completed geometry lessons, particularly on the Pythagorean Theorem. The research subjects consisted of 30 ninth-grade students selected through purposive sampling. The selection considered several criteria: students had studied geometry material, did not have special needs affecting spatial ability, and were willing to participate. The relatively small sample size is consistent with the requirements for pilot studies in Rasch-based instrument development, where 30–50 respondents are sufficient to estimate initial parameters and identify items needing revision [22]. Thus, the choice of research site and subjects was made by considering the relevance of the material, accessibility, and alignment with the study's objectives.

The research instrument was developed based on four indicators of spatial visualization ability proposed by Hass (1986): imagination, conceptualization, problem solving, and pattern recognition. The selection of these indicators was grounded in Hass's theoretical framework, which emphasizes that spatial visualization ability involves imagining forms or situations (imagination), forming mental concepts from spatial information (conceptualization), using spatial representation to find solutions (problem solving), and identifying geometric regularities or relationships (pattern recognition). These four indicators served as the main reference in preparing the test blueprint and developing the items. The instrument consisted of essay questions requiring students to explain their thinking processes in writing, supported by visual prompts to stimulate spatial reasoning. Each item was designed with a single clear idea, using precise and structured language, and demanding explicit spatial representation. This design was expected to represent students' competencies and facilitate the Rasch-based analysis comprehensively.

Content validation was conducted by one mathematics teacher and one mathematics education lecturer. The validation process aimed to review readability, the appropriateness of the items with the spatial visualization indicators, and the relevance of item contexts to students' developmental levels. The validation was carried out qualitatively through written feedback and suggestions, which were then used to revise the items to improve substance and language clarity. A pilot test was administered to 30 ninth-grade students, different from the main sample. The test was conducted in written form under controlled classroom conditions, with equal working time allotted for all students. Scoring was carried out by the researcher using a rubric developed beforehand. The rubric was arranged hierarchically to reflect the depth of students' responses according to the spatial visualization indicators. This procedure ensured that the instrument was not only theoretically valid but also empirically tested on a relevant group of respondents.

The test data were analyzed using Ministep software version 5.1.0.0 with the Rasch Model approach for polytomous data. The scores were coded numerically according to the rubric, organized in Excel format with columns containing respondent IDs and item scores, then imported into Ministep for calibration and estimation of item and person parameters. The analysis included examining Infit and Outfit Mean Square (MNSQ) values for each item within the acceptable range of $0.5 < MNSQ < 1.5$. Items outside this range were considered for revision or removal. In addition, item and person reliability as well as separation indices were analyzed. Person reliability with values ≥ 0.70 and item reliability ≥ 0.90 were expected to indicate good measurement consistency. Wright maps were further analyzed to evaluate the alignment between students' ability distribution and item difficulty levels. This analytical approach provided a comprehensive overview of the instrument's quality while identifying misfitting items for improvement.

As a summary of the research process, a flow diagram illustrating the stages of development, validation, pilot testing, and data analysis was presented to facilitate understanding of the sequence of activities. The use of the diagram was intended to emphasize the systematic nature of the study, enabling readers to clearly follow each stage while showing consistency between the objectives, procedures, and analyses conducted.

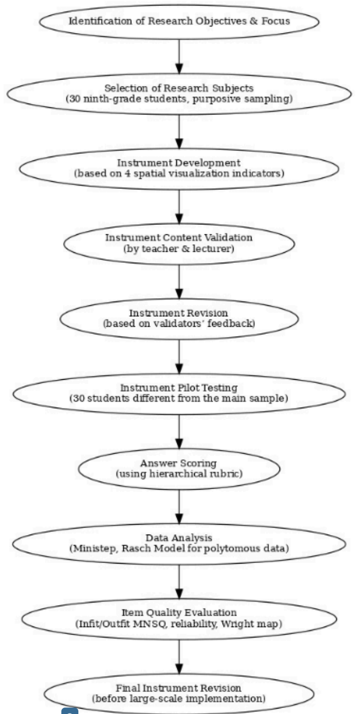

Figure 1. Research Flow Diagram

3. RESULTS AND DISCUSSION

3.1. Results

This study aimed to analyze the quality of spatial visualization test instruments using the Rasch Model approach. The analysis was focused on item validity, instrument reliability, and item difficulty index. Data were processed with the help of Ministeps 5.10.1.0 software, involving 30 students as respondents and 11 test items. The results of each analysis stage are presented sequentially to provide a comprehensive picture of the instrument's quality.

a. Item Validity Analysis

Item validity was examined based on three Rasch indicators, namely:

- Infit Mean Square (MNSQ) between 0.5 and 1.5
- Z-Standard (ZSTD) between -2.0 and +2.0
- Point Measure Correlation (Pt Measure Corr) between 0.4 and 0.85

The analysis results showed that out of 11 items, 5 met all three criteria and were declared valid, while 6 items failed to meet at least one criterion and thus required revision. This indicates that although several items have been well-constructed, there are still weaknesses in some items that must be addressed to improve the overall measurement accuracy.

Analysis Validity

```
TABLE 13.1 C:\Users\lapto\Downloads\uji coba ins ZOU671WS.TXT  Aug 01 2025 10:25
INPUT: 30 Person  11 Item  REPORTED: 30 Person  11 Item  4 CATS MINISTEP 5.10.1.0

Person: REAL SEP.: 6.63  REL.: .98 ... Item: REAL SEP.: 6.47  REL.: .98

        Item STATISTICS:  MEASURE ORDER
```

0,5 < MNSQ < 1,5
-2,0 < ZSTD < +2,0
0,4 < Pt Measure Corr < 0,85

ENTRY	TOTAL	TOTAL	JMLE	MODEL	INFIT		OUTFIT		PTMEASUR-AL		EXACT MATCH		
NUMBER	SCORE	COUNT	MEASURE	S.E.	MNSQ	ZSTD	MNSQ	ZSTD	CORR.	EXP.	OBS%	EXP%	Item
4	28	30	4.67	.45	1.09	.51	.79	-.45	.84	.57	46.7	72.9	4a
5	28	30	4.67	.45	1.09	.51	.79	-.45	.84	.57	46.7	72.9	4b
8	28	30	4.67	.45	1.09	.51	.79	-.45	.84	.57	46.7	72.9	6b
6	30	30	4.27	.45	.58	-2.53	.44	-1.81	.00	.56	96.7	74.0	5
10	30	30	4.27	.45	.58	-2.53	.44	-1.81	.00	.56	96.7	74.0	8a
11	30	30	4.27	.45	.58	-2.53	.44	-1.81	.00	.56	96.7	74.0	8b
3	45	30	-1.79	1.59	.01	-1.15	.01	-1.23	.98	.96	100.0	98.7	3
9	45	30	-1.79	1.59	.01	-1.15	.01	-1.23	.98	.96	100.0	98.7	7
1	59	30	-7.39	.43	2.60	5.86	3.21	5.44	.28	.84	30.0	72.2	1
2	62	30	-7.94	.43	.69	-1.76	.57	-1.68	.97	.84	86.7	72.6	2
7	62	30	-7.94	.43	.69	-1.76	.57	-1.68	.97	.84	86.7	72.6	6a
MEAN	40.6	30.0	.00	.65	.82	-.55	.73	-.65			75.8	77.8	
P.SD	13.8	.0	5.28	.44	.67	2.33	.83	2.00			25.9	9.9	

Description
Valid/retained
Valid/retained
Valid/retained
Invalid/revised
Invalid/revised
Invalid/revised
Invalid/revised
Invalid/revised
Invalid/revised
Invalid/revised
Valid/retained
Valid/retained

Figure 2. Item Validity Results Based on the Rasch Model

Figure 2 demonstrates that only a portion of the items fell within the acceptable tolerance limits, indicating the necessity of revising those outside the range. Hence, the revision process becomes an essential step to ensure the final instrument aligns with the Rasch Model standards.

b. Instrument Reliability Analysis

Instrument reliability was measured through Person Reliability and Cronbach's Alpha values. The results indicated:

- Person Reliability = 0.98 with separation = 6.63
- Cronbach Alpha (KR-20) = 0.91

These values confirm that the instrument achieved excellent internal consistency and was able to distinguish between students' ability levels significantly. The high separation index further suggests that the instrument can effectively categorize respondents into distinct ability groups.

Item Reliability Analysis

```
TABLE 3.1 C:\Users\lapto\Downloads\uji coba inst ZOU671WS.TXT  Aug 01 2025 10:25
INPUT: 30 Person  11 Item  REPORTED: 30 Person  11 Item  4 CATS MINISTEP 5.10.1.0
--------------------------------------------------------------------------------

     SUMMARY OF 30 MEASURED Person
-------------------------------------------------------------------------------
|          TOTAL                         MODEL         INFIT         OUTFIT    |
|          SCORE     COUNT     MEASURE   S.E.      MNSQ   ZSTD   MNSQ   ZSTD |
|-----------------------------------------------------------------------------|
| MEAN      14.9      11.0       -1.29     .82       .94    .05    .73    .07 |
|  SEM        .9        .0        1.07     .02       .06    .16    .07    .09 |
| P.SD       4.8        .0        5.76     .10       .34    .88    .39    .49 |
| S.SD       4.9        .0        5.86     .11       .35    .90    .40    .50 |
| MAX.      22.0      11.0        5.94    1.08      1.46   1.41   1.22    .53 |
| MIN.       9.0      11.0       -7.76     .72       .49  -1.12    .26   -.65 |
|-----------------------------------------------------------------------------|
| REAL RMSE    .86 TRUE SD    5.69  SEPARATION  6.63  Person RELIABILITY  .98 |
|MODEL RMSE    .82 TRUE SD    5.70  SEPARATION  6.94  Person RELIABILITY  .98 |
| S.E. OF Person MEAN = 1.07                                                  |
-------------------------------------------------------------------------------
Person RAW SCORE-TO-MEASURE CORRELATION = .99
CRONBACH ALPHA (KR-20) Person RAW SCORE "TEST" RELIABILITY = .91  SEM = 1.45
STANDARDIZED (50 ITEM) RELIABILITY = 1.00
```

Figure 3. Instrument Reliability Summary

The high reliability values show that the instrument is appropriate for measuring spatial visualization ability. However, despite the strong reliability, validity issues in some items remain, highlighting the importance of balancing both aspects in developing robust instruments.

c. Item Difficulty Index

The difficulty index was determined based on each item's logit value, with the following categorization:

- Logit > 1 → Difficult
- -1 ≤ Logit ≤ 1 → Moderate
- Logit < -1 → Easy

The analysis results showed:

- 5 items categorized as difficult (logit > 1)
- 3 items categorized as moderate (-1 ≤ logit ≤ 1)
- 3 items categorized as easy (logit < -1)

 https://doi.org/10.58421/misro.v4i3.682

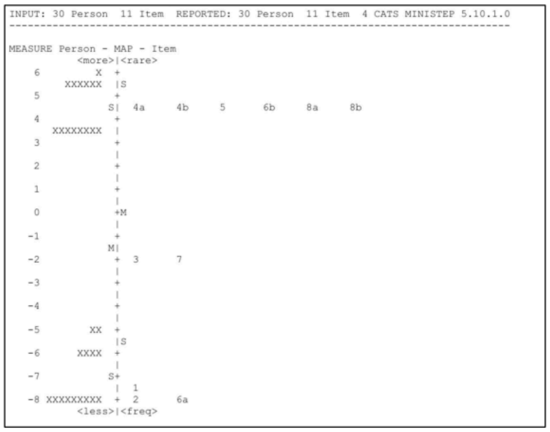

Figure 4. Item Difficulty Index

Table 1. Summary of Item Difficulty Index

Item No.	Logit	Category
1	-7.39	Easy
2	-7.94	Easy
3	-1.79	Easy
4a	4.67	Difficult
4b	4.67	Difficult
5	4.27	Difficult
6a	-7.94	Easy
6b	4.67	Difficult
7	-1.79	Easy
8a	4.27	Difficult
8b	4.27	Difficult

Distribution of difficulty levels in percentages:

- Difficult: 5/11 items (45.45%)
- Moderate: 3/11 items (27.27%)
- Easy: 3/11 items (27.27%)

The distribution indicates that the instrument tends to be dominated by difficult and easy items, while moderate items are relatively fewer. Items with extremely low logit values (e.g., -7.94) are too easy and less effective in differentiating student abilities. Conversely, extremely high logit values (e.g., 4.67) reflect items that are too difficult, which may hinder optimal measurement of students' abilities. Therefore, a rebalancing of item difficulty distribution is necessary to produce an instrument capable of fairly assessing students across a wide range of ability levels.

3.2. Discussion

The analysis results showed that some items in the instrument did not meet the validity criteria. This discrepancy was generally caused by several factors, such as unclear item construction, the use of contexts unfamiliar to students, or a mismatch between item difficulty and respondents' abilities. This condition indicates the need for item design revision so that they are more aligned with the indicators of spatial visualization ability being measured. These findings are consistent with Wiyarsi et al. [23], who emphasized that the Rasch Model is effective in identifying item weaknesses, thereby making the revision process more targeted. Thus, the validity of an instrument depends not only on theoretical item construction but also on the contextual relevance of the items to students' learning experiences.

The instrument's very high reliability demonstrates good internal consistency. However, high reliability does not always guarantee content validity, meaning revisions are still necessary to improve measurement accuracy. Studies by Wilberforce et al. [24] also confirmed that extreme logit values and invalid items can distort the representation of students' abilities. Therefore, eliminating or recalibrating problematic items becomes a crucial step before the instrument is used widely. This underlines that instrument quality must be viewed comprehensively, not solely from one statistical indicator, but from the integration of validity, reliability, and item appropriateness.

The distribution of item difficulty in this instrument tended to be unbalanced, dominated by difficult and easy items, while moderate items were relatively few. Such a distribution may reduce measurement precision as it fails to capture the full variation in students' abilities. Sihombing et al. [25] showed that a balanced proportion of difficulty levels can increase the sensitivity of instruments to student ability differences. In the context of mathematics assessment in general, paying attention to difficulty balance is crucial so that the instrument not only identifies students with high or low ability but also provides accurate information in the moderate range. Therefore, adding items with moderate difficulty becomes an urgent need in this instrument's development to ensure a more proportional mapping of students' abilities.

The limitations of this study must be acknowledged. The relatively small sample size and its restriction to students from one grade level and a single school limited the representativeness of the results. Moreover, the homogeneous learning context and student background may affect the generalizability of the findings. Therefore, further studies with larger sample sizes, more diverse backgrounds, and varied learning contexts are required to re-examine these results. Acknowledging these limitations is essential so that the interpretation of findings remains proportional and can serve as a foundation for future research.

More broadly, the implications of these findings emphasize that the development of mathematics assessment instruments, particularly those measuring spatial visualization ability, requires attention not only to reliability consistency but also to content alignment, difficulty level distribution, and conceptual representation. Well-calibrated instruments have the potential to become fair, accurate, and informative evaluation tools for both teachers and researchers in mapping students' abilities. In addition, such instruments can contribute to improving the quality of mathematics learning in junior high schools, as teachers will have objective benchmarks for designing learning strategies that match students' abilities.

4. CONCLUSION

This study produced a spatial visualization test instrument on the Pythagorean Theorem that demonstrated very high reliability; however, several items still require revision to achieve optimal validity. The limitations of this study lie in the unbalanced distribution of item difficulty levels and the pilot test being restricted to a specific population. This indicates that although the instrument has met reliability standards, validity quality, and balance in item difficulty remain challenges that must be addressed. Future development of the instrument should focus on achieving a more balanced difficulty distribution, adding items of moderate difficulty, and conducting trials with a larger and more diverse population. Accordingly, the instrument can serve not only research purposes but also provide teachers with a practical diagnostic tool to map students' spatial abilities. These findings contribute to the development of more adaptive, objective, and relevant diagnostic assessments for improving the quality of mathematics learning in junior high schools. Furthermore, the results of this study may serve as a foundation for curriculum developers to design data-driven instructional strategies that are better aligned with students' needs.

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