

# Diagnosing Students' Vector Concept Understanding Through Rasch Model Analysis

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**Abstract** - Accurate measurement of students' conceptual understanding of vectors requires assessment instruments with sound psychometric properties. This study aims to examine the validity, reliability, and item difficulty of a vector concept understanding instrument for high school students using Rasch model analysis. The study employed a descriptive quantitative design involving 30 high school students who had studied vector material. Data were collected through a 25-item multiple-choice test and analyzed using the Rasch model via Winsteps version 3.68.0. The results indicated that 15 items met the Rasch model fit criteria and could be retained as valid items, while 10 items required revision. The instrument demonstrated good internal consistency with a Cronbach's alpha of 0.83, item reliability of 0.81, and test-retest reliability of 0.75. Item difficulty analysis revealed a variation in difficulty levels capable of effectively distinguishing students' abilities. Items regarding vector components were found to be the most difficult concept for students to understand, whereas the concept of vector direction was relatively easier to grasp. These findings indicate that Rasch analysis is not only effective for evaluating instrument quality but also useful for identifying students' misconceptions and learning difficulties regarding vector material. Pedagogically, these research results can help teachers design more targeted learning strategies, particularly in strengthening students' understanding of vector components through visual and representational approaches. This study contributes to the development of diagnostic-based physics assessment and supports the use of the Rasch model as a robust approach in refining physics learning evaluation instruments.

**Keywords:** Conceptual Understanding; Physics Education; Rasch Model; Vector

## INTRODUCTION

Conceptual understanding is the main goal that students must achieve in the physics learning process. Students demonstrate good conceptual understanding when they can integrate prior knowledge and apply it correctly in new situations (Pratiwi et al., 2025). Without strong conceptual understanding, learning tends to rely on memorization and procedural strategies (Bao & Koenig, 2019). As a result, students struggle when faced with problems that require them to interpret concepts in different contexts.

One topic that often presents conceptual difficulties is vectors. An understanding of vectors plays a crucial role in many physics topics, including motion, force, momentum, and impulse. Students

with a weak understanding of vectors often struggle to solve problems in this area (Salmerón et al., 2025). Previous studies have reported low levels of conceptual understanding of vectors among students (Zavala & Barniol, 2010). Common difficulties include errors in vector addition and confusion between vector and scalar operations (Wutchana & Emarat, 2011). Understanding vectors requires interpreting magnitude and direction, as well as applying these properties in various physical situations (Latifa et al., 2021; Sabah, 2023). Many students struggle to connect vector representations with physical phenomena (Bollen et al., 2017; Hahn & Klein, 2023). Therefore, students' errors in vector concepts cannot be viewed merely as procedural weaknesses in mathematics, but

also as indicators of conceptual and representational difficulties.

To identify these conceptual difficulties, assessment tools capable of providing accurate diagnostic information are required. Many existing measurement tools are still evaluated using Classical Test Theory (CTT), which yields item statistics dependent on the sample and limits interpretation across various contexts (Andayani et al., 2019). This limitation reduces the assessment's ability to diagnose item function and students' conceptual difficulties at the item level (Fitriani et al., 2019). Therefore, a more robust measurement approach is needed.

To identify these conceptual difficulties, an assessment tool is needed that can provide accurate diagnostic information. Many existing measurement tools are still evaluated using Classical Test Theory, which produces item statistics that depend on the sample and limit interpretability in various contexts (Andayani et al., 2019). These limitations reduce the ability of assessments to diagnose item function and students' conceptual difficulties at the item level (Fitriani et al., 2019). Therefore, a more robust measurement approach is needed.

Classical Test Theory (CTT) and Item Response Theory (IRT) are frequently used to evaluate educational assessment tools. CTT is often used in evaluating assessment tools. However, the use of CTT yields item statistics that are dependent on the test sample (Kohli et al., 2015). This dependence limits the comparability of results across different groups. Conversely, the Item Response Theory (IRT) approach, particularly the Rasch model, allows for more objective estimates of student ability and item difficulty that are independent of the sample (Thomas, 2019; Tutz, 2024). Rasch analysis is particularly useful for

diagnosing conceptual understanding (Irawan et al., 2025; Nurani et al., 2025). In addition to evaluating the psychometric quality of the instrument, Rasch analysis can also be used to identify patterns of students' conceptual difficulties based on item responses, thereby providing stronger diagnostic value in research on conceptual understanding.

Various instruments have been developed to measure understanding of vector concepts, one of which is the Test of Understanding Vectors (TUV). Several previous studies have used the Rasch model or Item Response Theory (IRT) to evaluate the psychometric quality of vector instruments (Rafiah & Miyaqi, 2025; Rasyid et al., 2025; Susac et al., 2018). However, most studies have focused more on estimating reliability and general item characteristics, while analyses linking item functions to the diagnosis of students' conceptual difficulties remain limited. Furthermore, few studies have specifically examined how item difficulty levels can reflect students' obstacles in understanding vector representations, particularly in the context of high school physics education.

Given this situation, this study aims to address this research gap by not only evaluating the psychometric quality of the instrument using the Rasch model but also identifying the conceptual areas that students find most difficult to understand through an analysis of item difficulty levels. Thus, this study not only contributes to the development of physics assessment instruments but also provides diagnostic information that teachers can use to design more effective learning strategies related to vector material.

## RESEARCH METHODS

This study employed a quantitative descriptive survey design using the Rasch

model to evaluate the quality of an instrument measuring students' understanding of vector concepts (Cohen et al., 2007). A cross-sectional survey approach was applied, with data collected at a single point in time (Adiputra et al., 2021), using a 25-item multiple-choice test covering several vector subtopics. Data analysis was conducted within the Item Response Theory framework using the Rasch model, with Winsteps version 3.68.0 employed to examine item validity, reliability, and difficulty levels.

The sampling technique used in this study was purposive sampling, as respondents were selected intentionally based on specific criteria. The participants were 30 eleventh-grade students from SMAN 5 Malang who had completed vector instruction and met the minimum sample requirements for dichotomous Rasch analysis (Linacre, 1994). Student responses were scored dichotomously (1 for correct, 0 for incorrect) and the test items were adapted from established vector concept instruments in previous studies (Barniol & Zavala, 2014; Sari et al., 2017). Some questions have been modified to align with the high school curriculum and the students' context. This adaptation process included translation, linguistic refinement, and adjustments to visual representations. Content validity was evaluated by two faculty members specializing in physics education and an experienced physics teacher to ensure the relevance, clarity, and accuracy of the questions before they were implemented. The distribution of items across vector concepts is presented in Table 1.

Data were analyzed using the Rasch model to examine item validity, reliability, and difficulty. As shown in Table 2, item fit was evaluated using Infit and Outfit MNSQ statistics, with acceptable values ranging from 0.7 to 1.3 for dichotomous data, and

supported by positive Point Measure Correlation (PTMEA Corr) values of at least 0.3 (Bond & Fox, 2015). Instrument reliability was assessed using Cronbach's alpha as well as person and item reliability indices. Item difficulty is determined based on logit measurements and classified into four categories: very easy, easy, difficult, and very difficult based on the criteria of mean and standard deviation (Sumintono & Widhiarso, 2015).

**Table 1.** Subtopics of vector concept understanding instruments

Subtopics	Item
Vector notation and magnitude	S2,S4,S9,S24
Vector direction	S1,S3
Unit vector	S10,S23
Vector components	S5,S6,S7,S8,S22
Vector addition and subtraction	S11,S12,S13,S14,S15,S17,S21
Cross and dot multiplication	S16,S18,S19,S20,S25

**Table 2.** The square ranges for infit and outfit are some appropriate items.

Type of Test	Range
Multiple-choice test (high stakes)	0.8 – 1.2
Multiple-choice test (run of the mill)	0.7 – 1.3
Rating scale (Likert/survey)	0.6 – 1.4
Clinical observation	0.5 – 1.7
Judged (where agreement is encouraged)	0.4 – 1.2

## RESULTS AND DISCUSSION

A number of tests were conducted to evaluate the quality of the vector concept understanding instrument based on the Rasch model. First, conduct a validity test by determining item fit and item polarity. When assessing item fit in multiple-choice tests with dichotomous data, the Infit MNSQ parameter has to fall between 0.7 and 1.3. It was decided to use infit statistics because they are more sensitive in identifying mismatches those been that occur around the action capability level compared to outfit statistics, and are therefore considered more

appropriate c. In addition, the acceptable Z-Standard (ZSTD) value for the outfit and infit falls between -2.0 and 2.0. If the MNSQ value of infit and outfit is accepted, the ZSTD index value can be disregarded. Bond and Fox (2015) emphasized that a positive and 0.3 value or above for the Point Measure Correlation (PTMEA Corr) is required in order to determine item polarity.

The iterative item elimination procedure is based on Rasch measurement principles, which recommend recalibration after removing inappropriate items to obtain more stable parameter estimates and improve the consistency of construct measurement (Bond & Fox, 2015). Recalibration is performed at each iteration to analyze potential changes in the distribution of item difficulty levels and individual estimates. Analysis shows that the overall distribution of item difficulty levels remains relatively stable after recalibration, indicating that item removal does not significantly alter the measurement continuum or cause the data to be overly forced into acceptable statistical values. This step is continued until the most optimal statistics are obtained. Items that do not meet the established range and are discarded are presented in Table 3.

**Table 3.** Items retained and items dropped in rasch model analysis

Subtopics	Retained Item	Item Dropped
Vector notation and magnitude	S2 ,S24	S4,S9
Vector direction	S1,S3	-
Unit vector	S10	S23
Vector components	S5,S6,S8,S22	S7
Vector addition and subtraction	S12,S15,S17	S11,S13, S14,S21
Cross and dot multiplication	S16,S18,S19	S20,S25
<b>TOTAL</b>	<b>15 Item</b>	<b>10 Item</b>

Table 4 results demonstrate that the MNSQ Infit parameters fall within the acceptable range of 0.7 to 1.3, while the

constructed vector concept comprehension items fall within the range of 0.83 to 1.3. Because these 15 items have a positive PTMEA Corr score and are more than 0.3, they fall inside an acceptable range. This instrument's Cronbach's alpha rating of 0.83 suggests that it is very good reliability. Item reliability and individual reliability were recorded at 0.81 and 0.75, respectively. This means that although individual consistency in answering questions is quite good, while items show good reliability (Sumintono & Widhiarso, 2015).

**Table 4.** Results of items fit, item polarity, and level difficulty analysis using rasch model

Items	Measure	Infit		Ptmea Corr
		MNSQ	ZSTD	
S6	3.56	1.01	0.28	0.31
S16	2.12	1.25	0.68	0.36
S8	0.98	0.99	0.07	0.53
S3	0.69	0.83	-0.50	0.63
S17	-0.05	1.18	0.80	0.50
S18	-0.05	0.93	-0.22	0.60
S15	-0.26	1.30	1.38	0.42
S22	-0.47	0.90	-0.44	0.60
S10	-0.68	0.86	-0.68	0.62
S12	-0.68	1.07	0.41	0.53
S2	-0.88	0.91	-0.42	0.61
S5	-0.88	1.02	0.19	0.55
S19	-1.07	0.97	-0.10	0.58
S24	-1.07	1.07	0.41	0.53
S1	-1.27	1.00	0.06	0.58
P.SD		1.30		

Wright maps comparing item and person measurements are a visual representation of Rasch Model results. Figure 1 shows a Wright map where students' conceptual understanding abilities are spread on the left and the level of difficulty of the questions is spread on the right. Following that, valid questions are categorized according to their degree of difficulty derived from the item fit table. In the Rasch Model, fit items are listed in the item measure table and subsequently categorized according to the criterion for difficulty level. Based on Table 4, it shows

the largest logit value (+3.56) in question S6, sub-topic of vector components, and the smallest logit value (-1.27) in question S1, sub-topic of vector direction. Sorted by degree of difficulty, the items are classified as very difficult, difficult, and easy.

The results of the analysis show that several high-difficulty items are generally related to the concepts of vector components and translation between representations. This suggests that students' difficulties lie not only in mathematical calculations but also in the conceptual understanding required to connect vector diagrams, directions, and symbolic representations (Bollen et al., 2017). These findings are consistent with previous research showing that misconceptions in vector material often arise when students must determine vector orientation, project components, or distinguish between vector and scalar quantities (Wutchana & Emarat, 2011; Zavala & Barniol, 2010). Conversely, items with low difficulty levels tend to involve direct recognition of vector direction, thus requiring a simpler representational process.

On the wright map it shows that students 010 and 017 are students with the highest abilities, while student 022 is the student with the lowest abilities. The highest and lowest abilities of students are included in the normal category because they are within the range of two standard deviations (T) (Ringo et al., 2020).

The Wright Map analysis indicates that the distribution of item difficulty levels tends to be above the average student ability. This suggests that the instrument's targeting is not yet fully optimized, as some items are relatively too difficult for most participants (Bond et al., 2021). Additionally, there are several gaps in the item continuum, indicating inconsistencies in the distribution of item difficulty levels. These gaps may result in students' abilities within certain

ranges not being fully measured. This distribution also indicates a mismatch between student ability and item difficulty levels, suggesting that the instrument still requires the development of items with moderate difficulty levels to achieve a more balanced assessment. Nevertheless, the variation in item difficulty levels still provides important diagnostic information for identifying conceptual areas requiring additional learning support, particularly regarding visual representation and spatial reasoning in vector-related material.

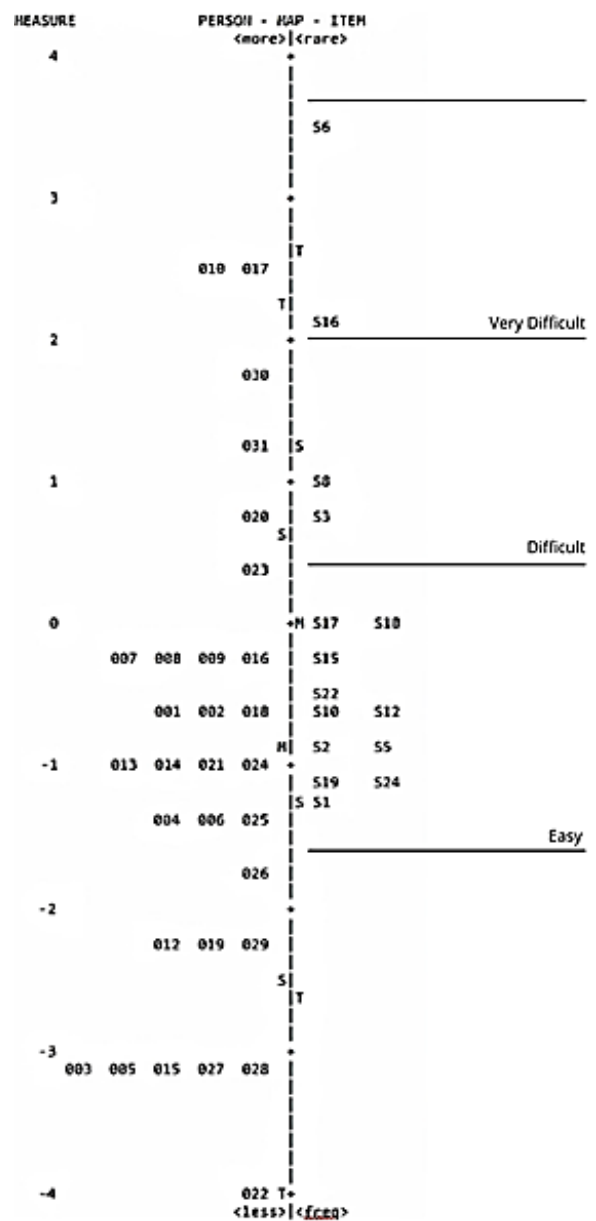


Figure 1. Wright map

The Rasch analysis indicates that the vector concept understanding instrument possesses adequate psychometric quality, as evidenced by acceptable item and person reliability indices. This finding aligns with the theoretical principle that reliable instruments can consistently differentiate levels of student ability and item difficulty (Bond & Fox, 2015). Consistent with previous research, instruments evaluated using Rasch modeling provide more precise diagnostic information compared to Classical Test Theory, enabling educators to identify specific conceptual difficulties (Manapsal, 2017; Nisfatulsanah & Sugiharto, 2024).

Item fit analysis revealed that some items did not conform to the Rasch model criteria, suggesting potential construct-irrelevant variance or ambiguity. Theoretically, items that misfit may fail to measure the intended construct, reducing the instrument's validity (Sumintono & Widhiarso, 2015). This observation is supported by prior studies reporting that vector concept items, particularly those involving symbolic manipulation or component decomposition, are prone to misinterpretation (Barniol & Zavala, 2014; Rakkapao et al., 2016; Sabah, 2023). Revising or removing these items is necessary to enhance construct validity and ensure that the instrument accurately reflects students' conceptual understanding.

The analysis of item difficulty shows that questions on vector components were the most challenging, while questions on vector direction were relatively easy. From a theoretical perspective, this aligns with cognitive load theory, as analytical tasks requiring calculation or decomposition demand higher cognitive processing than perceptual tasks (Chen et al., 2023). Similar patterns have been documented in previous research, where students exhibited persistent

difficulties in translating vectors into component forms (Ilahi et al., 2021; Walidain, 2020). This suggests that instruction should focus more on bridging conceptual understanding with procedural skills in vector decomposition.

The results of the study indicate that items related to vector components were the most challenging for students. From a cognitive perspective, the concept of vector components requires students to perform several mental processes simultaneously, such as visualizing the direction of a vector, determining its projection onto a specific axis, and translating visual representations into mathematical symbols. This difficulty indicates that understanding vectors depends not only on mathematical procedural skills but also on students' spatial representation and reasoning abilities. When students fail to connect diagrams with symbolic operations, misconceptions regarding the determination of vector components and operations tend to arise (Hoyer & Girwidz, 2024). Furthermore, the dominance of symbolic processing in problem-solving often leads students to focus more on manipulating formulas rather than understanding the physical meaning of vectors conceptually (Hahn & Klein, 2025).

The Wright Map shows that the overall difficulty of the items exceeds most students' ability levels, highlighting the instrument's sensitivity to higher-order conceptual understanding. This finding supports the theory of assessment alignment, which states that well-constructed instruments should target the intended range of cognitive ability (Andayani et al., 2019). Future refinements could balance item difficulty to provide more comprehensive measurement across all ability levels, enhancing the instrument's utility for both diagnostic and formative purposes.

## CONCLUSION

This study shows that a Rasch analysis-based vector concept comprehension instrument is not only suitable for use as an assessment tool but also effective in diagnosing students' conceptual difficulties with vector material. The greatest difficulty was found in the concept of vector components, indicating that students still face challenges in connecting mathematical representations with visualizations of vectors. These findings indicate the need for instruction that places greater emphasis on the use of diagrams, visual representations, and gradual practice in component analysis. Thus, this instrument can help teachers identify students' misconceptions and design more targeted instruction. This study is still limited to a relatively small sample size. Therefore, further research with a broader range of respondents and optimal item revision is needed to strengthen the diagnostic capabilities and accuracy of the instrument.

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