Journal of Educational Sciences Vol. 8 No. 3 (July, 2024) 349-361

Journal of Educational Sciences
Journal homepage: https://jes.ejournal.unri.ac.id/index.php/JES

P-ISSN 2581-1657
E-ISSN 2581-2203

Students' Mathematical Representation Ability Assessment Instrument Development in the Three-Dimensional Topics on the 12th grade of Senior High School

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ARTICLE INFO

Article history:

Received: 14 Nov 2023
Revised: 01 July 2024
Accepted: 03 July 2024
Published online: 24 July 2024

Keywords:

Mathematical Representation Ability;
Instrument;
Assessment

A B S T R A C T

The fact that students' mathematical representation abilities are still relatively low is an issue that continues to this day in the education sector. One of the factors that influence this issue is the lack of evaluation and habituation of students in solving mathematical problems that facilitate mathematical representation abilities. Good instruments certainly need to support these evaluation and habituation efforts. This research aims to produce an instrument for assessing students' mathematical representation abilities that meets criteria that are valid, reliable, have a good discriminatory item value, and good level of difficulty. This development research uses the Borg and Gall development model, which is carried out up to the main fields testing stage. From the research results, a set of instruments for assessing representational ability in Three - Dimensional topic which amounted to 15 questions, with 8 questions in Question Package 1 and 7 questions in Question Package 2, which met the criteria for validity, reliability, and have a good discriminatory item value with a good level of difficulty too. The instrument for assessing students' mathematical representation abilities was developed from these results and met with good final results.

1. Introduction

The National Council of Teachers of Mathematics (NCTM) states that there are five standards for mathematical abilities that students must have, one of which is mathematical representation abilities (Hadiastuti & Soedjoko, 2019). Mathematical representation has several types, including visual representation, symbolic representation, and verbal representation (Puspitasari & Susanah, 2022 ; Musrikah et. al., 2023). Mathematical representation ability is the ability to communicate mathematical ideas through various forms such as pictures, tables,

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graphs, numbers, letters, symbols, and other representations to solve mathematical problems (Hardianti & Effendi, 2021). Syafri (2017) also states that mathematical representation ability is the ability to express mathematical ideas (problems, statements, definitions, etc.) in various ways. Therefore, it can be concluded that the ability to represent mathematically is an ability to communicate ideas in various forms or certain ways, both visual, verbal, and symbolic mathematics. Mahendra (2019) also added that mathematical representation abilities are important in helping students improve their understanding of mathematical concepts so that they can solve math problems well. Referring to the importance of mathematical representation abilities, these abilities must always be evaluated and trained for students so that they are accustomed to working on problems that support students' representation abilities.

To assess the mathematical representation abilities of students, indicators are needed that demonstrate the extent to which students can utilize these representations. Language is an important tool to express and communicate with the others (Sari, 2023). The indicators of mathematical representation abilities to be used in this study are those presented by NCTM, as mentioned in Putri (2020) which are: (1) Creating and using representations to organize, record, and communicate mathematical ideas. (2) Selecting, applying, and translating mathematical representations to solve problems. (3) Using representations to model and interpret physical, social, and mathematical phenomena.

Based on the results of a study by the Program for International Student Assessment (PISA) on 2018, Indonesia was ranked 74th out of 79 countries (Sugianto et al., 2020 ; Pramana et al., 2021). The latest study from PISA on 2022 also showed that in the mathematical aspect Indonesia was ranked 69th out of 81 countries, and experienced a decrease in score by 13 points compared to the average international score decrease of 21 points (OECD, 2023). One of the mathematical contexts tested in the PISA assessment is mathematical representation ability (Stacey & Turner, 2015). Continuing Professional Development is provided institutionally, teachers will get the opportunity to develop professionally, and students will also be benefited through it (Afroz, 2024). Mathematics is often considered a difficult subject to understand, both theory and application, and one of which is geometry. In addition, it was also found that students’ abilities on geometry topics had not reach the expected geometry learning goals (Roza et al., 2017 ; Sari et al., 2020).

The results of research in line by Utami (2019) inform that most students still have low mathematical representation abilities on geometry topics, which is 45.46%. The difficulties students encounter in three-dimensional geometry are evidenced by the errors they make when attempting to solve problems about three-dimensional geometry (Nasrulloh & Sugandi, 2023). One of significant factor contributing to the low mathematical representation ability of these students is the lack of evaluation and habituation of students in solving problems that require mathematical representation abilities (Ulya & Rahayu, 2021). This information leads to the conclusion that students' mathematical representation abilities, particularly in three-dimensional topics, are still considered to be relatively low. For this reason, teachers should be encouraged to try to familiarize students with completing learning tasks in the form of visual, verbal, and symbolic representations, and in order to make students' representation abilities easier to observe, the questions or forms of tests given should be more of a description test (Sukardi & Handayani, 2022)

According to Ramadhani (2021) one of the strategies to improve students' mathematical abilities is by evaluating and habituating students with solving mathematical problems, particularly their mathematical representation abilities. To achieve the desired evaluation and habituation outcomes, it is necessary to have an effective or good assessment instruments aligned with indicators of mathematical representation. The assessment instrument can be considered good if it at least meets the criteria or by fulfilling the status of validity, reliability, and has a good discriminatory item value and difficulty levels (Arifin, 2016).

Based on the above information and rational considerations regarding the importance of assessment instruments that support students' mathematical representation abilities, it is important to develop of assessment instruments on mathematical representation abilities in the three-dimensional topics for students of 12th grade of high school. With the development of an assessment instrument for mathematical representation abilities that meets criteria for validity, reliability, and has good discriminatory item value and difficulty levels, it is hoped that it can be used by teachers and students to further develop students' mathematical representation abilities.

2. Methodology

Research and development (R&D) aim to produce a product, a set of mathematical representation ability assessment instruments on three- dimensional topics for students of 12^{th} grade of high school. The research design of this development refers to the steps of research and development by Borg and Gall modified by Sugiyono (2019) which consists of: (1) Research and Information Collection, (2) Planning, (3) Develop Preliminary form of Product, (4) Preliminary Field Testing, (5) Main Product Revision, (6) Main Field Testing, (7) Operational Product Revision, (8) Operational Field Testing, (9) Final Product Revision, and (10) Dissemination and Implementation. This research was only carried out up to stage 6, the main field testing.

The subjects of this research were students of 12^{th} grade from high school with research data in the form of qualitative data and quantitative data. Qualitative data was obtained from the suggestions from validators and students on the assessment instrument that was developed. Quantitative data were obtained from the results of internal validation by three validators, and the scores from the instrument test results for assessing mathematical representation abilities in three-dimensional topics who carried out by students.

At the research and information collection stage, various information collection and analysis are carried out to find out the urgency of the research conducted. Furthermore, at the Planning stage, product design and data collection sheets are carried out. After the product is designed, the product is completed or realized and tested for internal validity at the develop preliminary form of product stage. Analysis of internal validation data using formulas and categories:

$$\bar{M}_v = \frac{\sum_{i=1}^{n} \bar{V}_i}{n}$$

Description:
$\bar{M}_v$: the overall average validity
$\bar{V}_i$: the average validity by validators
n : sum of validators

Interpretation Classification of Internal Validity can be seen in Table 1.

Table 1. Interpretation Classification of Internal Validity

Internal Validation Value Range	Interpretation
$1,00 \leq \bar{M}_v < 1,75$	Invalid
$1,75 \leq \bar{M}_v < 2,50$	Less Valid
$2,50 \leq \bar{M}_v < 3,25$	Valid
$3,25 \leq \bar{M}_v \leq 4,00$	Very Valid

Source: (Arikunto, 2018)

Products that have been assessed as internally valid are then tested on a limited basis to students and analyzed for readability using a student response questionnaire at the preliminary fields testing stage. Analysis of students' response questionnaire data using formulas and categories:

$$V_p = \frac{T_{sp}}{T_{sh}} \times 100\%$$

Description:
V_p : respondent score
T_{sp} : empirical total score of respondents
T_{sh} : the maximum expected total score

Students' Response Criteria can be seen in Table 2.

Table 2. The Students' Response Criteria

Respondents' Score Presentation	Interpretation
0-20	Bad
21-40	Not good
41-60	Moderately good
61-80	Good

Source: (Sa'adah et al., 2019)

Suggestions and comments from students at the preliminary field testing stage are taken into consideration at the main product revision stage with the aim of improving the product so that it is ready to be tested on a larger scale. The test to students on a larger scale was carried out at the main field testing stage. At the main field testing stage, the scores of students' results were obtained which then became the basic data in analyzing external validation, reliability, discrimination items, and the level of difficulty of test.

a. External Validation Data Analysis

External validation analysis aims to see the functionality of an instrument before it is tested on a representative sample (Farida & Musyarofah, 2021). Analysis of external validation data using the formula and category:

$$r_{xy} = \frac{n\sum XY - (\sum X)(\sum Y)}{\sqrt{(n\sum X^2 - (\sum X)^2 . (n\sum Y^2 - (\sum Y)^2)}}$$

Description:

r_{xy} : correlation coefficient value

X : the item score of the questions

Y : the total score of each question

t test with formula

$$t_{count} = r_{xy}\sqrt{\frac{n-2}{1-r_{xy}{}^2}} \;\; ; t_{table} = t_{\propto}(df = n-2)$$

If $t_{count} > t_{table}$, the question item is considered valid, or

Jika $t_{count} \leq t_{table}$, the question item is considered invalid.

b. Assessment Instrument Reliability Analysis

The definition of reliability according to classical theory means how far the measurement results can be trusted and believed to be accurate (Nusantari, 2016). Analysis of the reliability of the instrument is calculated using the internal consistency method where this calculation only requires one presentation of the test (Purwanto, 2016). Reliability analysis using the formula and categories:

$$r_i = \left(\frac{k}{k-1}\right)\left(1 - \frac{\sum \sigma_i^2}{\sigma_t^2}\right)$$

Description:

r_i : reliability value

k : the total of question items

$\sum \sigma_i^2$: the sum of item variances

σ_t^2 : total variance

The Reliability Criteria can be seen in Table 3.

Table 3. Reliability Criteria

Reliability Value Range	Interpretation
$0{,}00 \leq r_i < 0{,}20$	Less Reliable
$0{,}20 \leq r_i < 0{,}40$	Rather Reliable
$0{,}40 \leq r_i < 0{,}60$	Quite Reliable
$0{,}60 \leq r_i < 0{,}80$	Reliable
$0{,}80 \leq r_i \leq 1{,}00$	Very Reliable

Source: (Riyani et al., 2017)

c. Analysis of the Discriminatory Item of the Assessment Instruments
Discriminatory item of the assessment instruments is the ability of individual questions to distinguish between students who have a good understanding of the topic being tested and those who do not (Fatimah & Alfath, 2019). Analysis of discrimination items using the formula and categories:

$$DP = \frac{\bar{x}\ Na - \bar{x}\ Nb}{s_{max}}$$

Description:
DP : discrimination item value
$\bar{x}\ Na$: upper group average
$\bar{x}\ Nb$: lower group average
s_{max} : the maximum score of the question

The Classification of Discrimination Item of the Assessment Instrument Interpretation can be seen in Table 4.

Table 4. Classification of Discrimination Item of the Assessment Instrument Interpretation

Discrimination Item Value Range	Interpretation
$DP \leq ,00$	Very bad
$0{,}00 < DP \leq 0{,}20$	Bad
$0{,}20 < DP \leq 0{,}40$	Moderate
$0{,}40 < DP \leq 0{,}70$	Good
$0{,}70 < DP \leq 1{,}00$	Very good

Source: (Azmi, 2019)

d. Analysis of the Difficulty Level of the Assessment Instrument
Analysis of the level of difficulty using the formula and categories:

$$IK = \frac{\bar{x}Bs}{s_{max}}$$

Description:
IK : Index of difficulty
$\bar{x}Bs$: The average score of test on certain items
s_{max} : The maximum score of the question

The Classification of the Difficulty Level of the Assessment Instrument Interpretation can be seen in Table 5.

Table 5. Classification of the Difficulty Level of the Assessment Instrument Interpretation

Index of Difficulty Range	Interpretation
$IK = 0{,}00$	Too difficult
$0{,}00 < IK \leq 0{,}30$	Difficult
$0{,}30 < IK \leq 0{,}70$	Medium
$0{,}70 < IK < 1{,}00$	Easy
$IK = 1{,}00$	Too easy

Source: (Erfan et al., 2020)

3. Results and Discussion

Research and Information Collection

Referring to the research stages that have been explained, here will be described the results of the research obtained. The research and information collection stage carried out by analyzing several aspects, including needs analysis, student analysis, and curriculum analysis. From the results of this analysis, it was found that the development of an instrument for assessing the mathematical representation ability of students in three-dimensional topics was needed by students of 12th grade of high school by the 2013 curriculum, and the indicators of mathematical representation ability by NCTM.

Planning

At the planning stage, the design of the developed product is carried out and it is obtained: the design of questions with the type of questions in the form of descriptions test at the cognitive level of C3 (apply), C4 (analyze), and C5 (evaluate) while keeping in focus on the ability of mathematical representation; the question matrix which contains: the identity of the matrix of test, basic competencies, learning topics, indicators of competency achievement and the type of representation to aim for, the indicator of the question, the question of the test, the description of the type of question, and the question number; alternative solutions and scoring guidelines for assessing mathematical representation ability; as well as internal validation questionnaires and student response questionnaires. The final product consists of a set of assessment instruments comprising 20 questions that evaluate mathematical representation abilities, which are organized into 2 distinct question packages.

Develop Preliminary Form of Product

The products that have been designed are then finalized into a complete set of mathematical representation ability assessment instruments and tested for theoretical or internal validity by 3 validators at the preliminary form of the product stage. A set of products from the results at this stage is called prototype 1. A recapitulation of the average score of the internal validation assessment of the student's mathematical representation ability assessment instrument on three-dimensional topics assessed by three validators was obtained can be seen in Table 6.

Table 6. Internal Validation Calculation Results

	Aspect				Category
	Content/ Topics	**Construction**	**Language**	**Mathematical Representation**	
The Average Score from Package Question 1	3,94	3,78	3,80	3,79	
The Average Score from Package Question 2	4,00	3,85	3,82	3,84	
The Total Average	3,85				Very Valid

From Table 6, it is shown that the total average score of validation in all four aspects is 3,85. Based on the criteria in Table 1, it is concluded that the instrument for assessing students' representation ability in the three-dimensional topics on the 12th grade of high school is qualified theoretically or internally valid.

Preliminary Field Testing

Products or prototype 1 that have been validated and revised based on suggestions by validators are then tested on a limited basis at the preliminary fields testing stage. This limited testing was carried out on a total of 6 students. At this preliminary fields testing stage, students were asked to work on assessment questions on the mathematical representation ability of three-dimensional topics and then asked to provide comments and input through the student response questionnaire. The results of the questionnaire obtained an average percentage of 79.7% in the category of good. These results indicate that the mathematical representation ability assessment questions on the Three- Dimensional topics get a positive response from students and can be considered to be good in terms of readability.

Main Product Revision

Suggestions and comments from students at this stage were taken into consideration at the main product revision stage to improve the mathematical representation ability assessment questions and produce prototype II.

Main Field Testing

The test was then carried out again on students who were the subject of research at the main fields testing stage. The main fields testing stage was carried out on 30 students. The scores or students' results from the test on the main fields testing stage then became the basic data in calculating the external validity, reliability, discriminatory item, and difficulty level of the mathematical representation ability assessment instrument on the three-dimensional topics.

a. External Validation Data Analysis

The external validity test was carried out using the Pearson product moment formula to obtain the correlation coefficient value of each item which was then tested using the t test. The t_{count} value of each item is compared with the t_{table} with the provisions of the $t_{table} = t_{\propto}(df = n - 2)$ and the significance level is 95%. The item of question is considered valid $t_{count} > t_{table}$ and considered invalid if $t_{count} \leq t_{table}$. The results of the external validity test for 10 mathematical representation ability assessment questions for 2 question packages with $t_{table} = t_{\propto}(df = 30 - 2) = 2{,}048$ are presented in Table 7.

Table 7. Calculation Results of Item Validity Test

Question Package 1			**Question Package 2**		
QuestionsNumber	t_{count}	**Category**	**QuestionsNumber**	t_{count}	**Category**
1	2,75	Valid	1	3,54	Valid
2	2,25	Valid	2	2,97	Valid
3	3,93	Valid	3	4,08	Valid
4	2,22	Valid	4	2,11	Valid
5	2,42	Valid	5	3,42	Valid
6	1,80	Invalid	6	3,69	Valid
7	3,40	Valid	7	3,60	Valid
8	2,78	Valid	8	3,00	Valid
9	3,46	Valid	9	2,90	Valid
10	3,13	Valid	10	3,33	Valid

From the results of the calculation of the external validity test in Table 7, it show that out of 20 questions about the assessment of mathematical representation ability consisting of 10 questions of question package 1 developed, 9 questions that are categorized as valid and 1 question that is categorized as invalid, which is question number 6. The questions that are categorized as invalid are not included in the reliability test, discriminating item, and difficulty level.

b. Assessment Instrument Reliability Analysis

The reliability test has been conducted using the Cronbach's Alpha formula. The reliability test value was obtained 0,735 for the question package 1 and 0,814 for the question package 2. Based on the reliability criteria in Table 3, the reliability criteria found are high for the question package 1 and very high for the question package 2. It can be concluded that the representation ability assessment question on the three- dimensional topics is a reliable product.

c. Analysis of the Discriminatory Item of the Assessment Instruments

The discriminatory item of the mathematical representation ability assessment questions on three-dimensional topics which was developed obtained the results presented in Table 8.

Table 8. Calculation Results Discriminatory of Item

Question Package 1			Question Package 2		
Questions Number	***DP***	**Category**	**Questions Number**	***DP***	**Category**
1	0,29	Moderate	1	0,49	Good
2	0,32	Moderate	2	0,39	Moderate
3	0,21	Moderate	3	0,22	Moderate
4	0,22	Moderate	4	0,13	Bad
5	0,22	Moderate	5	0,33	Moderate
6	0,18	Bad	6	0,29	Moderate
7	0,33	Moderate	7	0,21	Moderate
8	0,17	Bad	8	0,19	Bad
9	0,33	Moderate	9	0,42	Good
10	0,22	Moderate	10	0,19	Bad

Based on Table 4, the results of Table 8 show that there was 1 question categorized as having poor or bad for discrimination of item and 8 questions categorized as sufficient or moderate in question package 1. It also showed that there were 3 questions categorized as having poor or bad for discrimination of item, 5 questions categorized as sufficient or moderate, and 2 questions categorized as having good for discrimination of item in question package 2. Item of questions that fall into the category of having poor or bad for discrimination of item will be eliminated, therefore the items for the assessment of mathematical representation ability in the three-dimensional topics will be eight items in question package 1 and seven items in question package 2.

d. Analysis of the Difficulty Level of the Assessment Instrument

The level of difficulty of the mathematical representation ability assessment questions on the three-dimensional topics that was developed obtained the results presented in Table 9.

Table 9. Calculation Results of Problem Item Level of Difficulty

Question Package 1			Question Package 2		
Questions Number	***IK***	**Category**	**Questions Number**	***IK***	**Category**
1	0,48	Medium	1	0,73	Easy
2	0,61	Medium	2	0,64	Difficult
3	0,41	Medium	3	0,27	Difficult
4	0,32	Medium	4	0,27	Difficult
5	0,27	Difficult	5	0,25	Difficult
6	0,28	Difficult	6	0,10	Difficult
7	0,22	Difficult	7	0,10	Difficult
8	0,13	Difficult	8	0,10	Difficult
9	0,15	Difficult	9	0,34	Medium
10	0,12	Difficult	10	0,13	Difficult

Based on Table 5, the results in Table 9 show that 4 questions are categorized as having a medium level of difficulty, and 4 questions are categorized as difficult in question package 1. It is also shown that there is 1 question that is categorized as having an easy level of difficulty, 2 questions that are categorized as medium, and 4 questions that are categorized as difficult in question package 2.

4. Conclusion

Based on the results of the research and discussion, it can be concluded that the set of questions of the instrument for assessing the representation abilities of students in the Three- Dimensional topics in the 12th grade of high school which was developed using the research and development (R&D) model according to Borg and Gall can be categorized as a good assessment instrument by meeting the criteria for being valid both internally and externally, being reliable and having good discriminatory item value with good level of difficulty. The results of this research can be used by various educational practitioners, especially teachers in developing instruments for assessing students' mathematical representation abilities to help monitor and develop students' mathematical representation abilities by building habits in solving on problems based on mathematical representation abilities for better educational purposes.

Acknowledgement

Thank you and great appreciation to the all researches who collaborated in producing this product. We also want to express our appreciation to all colleague, teachers, and student who were involved in the process of validating and testing of this product.

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How to cite this article:

Hardy, N., Armis., & Saragih, S. (2024). Students' Mathematical Representation Ability Assessment Instrument Development in the Three-Dimensional Topics on the 12th grade of Senior High School. *Journal of Educational Sciences*, *8(3)*, 349-361.