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The Development of an Instrument on Negative Fractions to Measure the Cognitive Obstacle Based on Mental Mechanism Stages

Susiswo Susiswo¹, Tatik Retno Murniasih², Cholis Sa'dijah¹,
Makbul Muksar¹, Wasilatul Murtafiah³

¹Universitas Negeri Malang, Jl. Semarang No. 5, Malang, Indonesia

²Universitas PGRI Kanjuruhan Malang, Jl. S. Supriadi No.48, Malang, Indonesia

³Universitas PGRI Madiun, Jl. Setiabudi No. 85, Madiun, Indonesia

Abstract – The cognitive obstacle is a thinking barrier of pre-service teachers caused by less meaningful learning and the difficult nature of fraction material. The pre-service teachers' cognitive obstacle measurement is done by giving negative fraction questions that contradict positive fractions. This research objective is to develop an instrument that can measure cognitive obstacles based on mental mechanism stages. This development research uses three stages of 4D development: defining, designing, and developing. The research participants were 71 pre-service teachers from two different universities in Malang, Indonesia. The research findings show that questions of a negative fraction have a high level of validity in measuring the cognitive obstacle of pre-service teachers. Triangulation is recommended for further research related to cognitive obstacles that arise when solving fraction problems of negative numbers.

Keywords – instrument, negative fraction, cognitive obstacle, mental mechanism

1. Introduction

The cognitive obstacle is a barrier to one's thinking when facing new contradictory problems [1]. The

cognitive obstacle in learning material of fractions can be caused by less meaningful learning [2] and the difficult nature of fraction material [3],[4],[5].

People with cognitive obstacle have several characteristics such as generalizing the knowledge obtained to prior experience, relying on false intuition, and having a problem with language representation [6],[7],[8]. Poor understanding of positive fractions will hinder someone from learning negative fractions. Based on these characteristics, people thinking process will be hampered when facing a contradictory problem. For example, a problem in positive numbers will contradict with negative numbers [1].

Several researchers had examined the cognitive obstacle on positive number fractions. Research in Japan showed that untreated students had problems understanding the equal-whole of positive fractions [3]. Research in Canada showed that pre-service teachers were still experiencing cognitive obstacles when building a meaningful solution in solving positive fractions [4]. Meanwhile, several studies in Indonesia showed that cognitive obstacles occurred when solving positive fractions, such as misconceptions about fraction density and obstacle related to language representation [9],[10],[11].

It is necessary to develop an instrument to measure the cognitive obstacle of pre-service teachers on negative fractions learning material. Most of the pre-service teachers still make many mistakes in solving negative fractions [12]. The instrument being developed refers to 3 characteristics of cognitive obstacles.

The negative fraction instrument is an instrument that contradicts a positive fraction. The different signs between positive and negative will lead to a contradictory concept [13],[14],[15]. The contradictory concept leads to cognitive obstacles [1],[16].

The cognitive obstacle can be measured based on the stages of the mental mechanism of APOS. The mental mechanism stages consist of interiorization,

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Corresponding author: Susiswo Susiswo,
Universitas Negeri Malang, Malang, Indonesia.
Email: susiswo.fmipa@um.ac.id

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coordination, reversal, encapsulation, and de-encapsulation [17]. The cognitive mechanism stages can be used to analyse pre-service teachers' understanding of fractions [17],[18],[19]. The experts' presentation explained why the pre-service teachers' cognitive obstacle on fraction problems could be analysed by the mental mechanism stages of the APOS theory.

The obstacle being experienced by pre-service mathematics teachers in Malang when facing negative fractions becomes the main problem of this research. The development of an instrument on negative fractions is needed to measure the cognitive obstacle. This research aims to develop a negative fraction instrument that can measure cognitive obstacles based on the mental mechanism stages. The instrument is developed based on cognitive obstacle indicators, including false intuitive obstacles, generalization obstacles, and language representation obstacles.

2. Method

The development framework refers to the 4D development stages by Thiagarajan [20]. This research type is development research. The instrument is developed to measure cognitive obstacle applies three stages of 4D development, namely defining, designing, and developing.

The defined stage includes several activities, including front-end analysis, pre-service teacher analysis, material analysis, and test analysis. The front-end analysis is a literature study on fractions given at the university to measure cognitive obstacles as instrument design and development according to the mental mechanism stages. The pre-service teachers' characteristics are used to analyse the development of instrument on negative fractions material. The material is analysed in detail to identify the material according to the curriculum in higher education. The test is designed to bring up the pre-service teachers' cognitive obstacle related to negative fractions according to the mental mechanism stages. The design stage includes the development of an instrument that can measure the pre-service teachers' cognitive obstacle. The activities include analysing the learning objective and analysing the pre-service teachers at two private universities in Malang, generating a test grid. The cognitive obstacle indicators are adjusted to mental mechanism stages. The development stage is carried out in two steps, namely expert validation and development trials/testing. The development stage aims to produce the final instrument after going through expert revisions and trials.

The research subjects were 71 pre-service teachers from 2 private universities in Malang City, Indonesia. The pre-service teachers in question had already finished the course of Mathematical Foundation and School Mathematics Development

Studies 1. Both classes instill an understanding of numbers so that the candidates have sufficient cognitive knowledge to solve fraction problems [16]. The candidates were selected based on various abilities they already have. The research used several instruments, including tests, assessment scores, and validation. The test was arranged according to cognitive obstacles' characteristics, including language representation obstacle, generalization obstacle, and false intuitive obstacle. The test consisted of 2 fraction questions developed on negative numbers. The test instrument's development referred to the indicators of cognitive obstacles seen in Table 1.

Table 1. Indicators of the cognitive barrier according to mental mechanism stages

Problem	Barrier Indicator	Mental Mechanism
1.	- Understand the sentence "the fraction will produce a value closest to one but not equal to one" as an integer that is closest to one but not equal to one	Interiorization
	- Understand the sentence "the fraction will produce a value closest to one but not equal to one" as a fraction that has the distance of zero from one	
	- Understand the sentence "the fraction will produce a value closest to one but not equal to one" as a fraction before one	
2.	- Understanding $C - D = D$ as everything minus D will result in D	Coordination
1.	- Coordinating the component of numbers, including 1, 3, -4, and -7	
	- Coordinating the component of numbers, including 1, 3, -4, and 6	
	- Coordinating the component of numbers, including 1, 3, 6, and 8	
2.	- Confused about estimation	
	- Confused about partitions on different lines of number	
	- Not using $-1/2$, 0, and $1/2$ as benchmarks	
1.	- Associates with an integer so that the numerator minus the numerator and denominator minus the denominator	Reversal
	- Relate and generalize with the example of $C - D = D$	
	- Process of setting $\frac{3}{1} - \frac{-7}{-4}$	
1.	- Process of setting $\frac{1}{5} - \frac{3}{-4}$	n
	- Process of setting $\frac{1}{3} - \frac{-4}{6}$	

Problem	Barrier Indicator	Mental Mechanism
2.	<p>- The process of determining all pairs of subtractions that give G, namely: A – G = G, B – G = G, C – G = G, D – G = G, E – G = G, and F – G = G</p> <p>- The process of determining H – G = G and G – E = G</p>	De-encapsulation
	<p>- The process of questioning back $\frac{3}{1} - \frac{-7}{-4} = \frac{3-(-7)}{1-(-4)} = \frac{3+7}{1+4} = \frac{10}{5} = 2$, closest to 1</p>	
1.	<p>- The process of questioning back $\frac{1}{5} - \frac{3}{-4} = \frac{4+15}{20} = \frac{19}{20}$ is closest to 1</p> <p>- The process of questioning back that $\frac{1}{3} - \frac{-4}{6} = \frac{1}{3} + \frac{4}{6} = \frac{2+4}{6} = \frac{6}{6} = 1$, one is the closest to one without rereading the question</p>	
2.	<p>- The process of questioning back that all pairs of subtraction from G will yield G</p> <p>- The process of questioning again that H and G must be positive numbers</p>	

The instrument test being developed is adapted from [21],[22]. The two developed test questions are presented in Table 2.

Table 2. Instrument being developed

No.	The test developed on negative numbers
1.	<p>Make two fractions (both the numerator and denominator contain one number only)! The numbers provided to form the two fractions are 1, 3, -4, 5, 6, -7, and 8. Each number can only be used once. Subtracting the two fractions will produce a value that is closest to one but not equal to one.</p> <div style="display: flex; align-items: center; justify-content: center;"> <div style="border: 1px solid black; width: 40px; height: 40px; margin: 5px;"></div> <div style="border: 1px solid black; width: 40px; height: 40px; margin: 5px;"></div> <div style="margin: 0 10px;">-</div> <div style="border: 1px solid black; width: 40px; height: 40px; margin: 5px;"></div> <div style="border: 1px solid black; width: 40px; height: 40px; margin: 5px;"></div> </div>
2.	<p>Given that A, B, C, D, E, F, G, and H each represent a number on the number line. Each number can be subtracted, for example, C - D = D (by estimation). Using the estimation, write down all pairs of subtraction that give the value G (in the Figure below)!</p>

The second instrument being developed is the assessment score. The appropriate instrument assessment score can be seen in Table 3. below.

Table 3. Assessment scores according to mental mechanism stages

No.	Answer	Score
1	Correct up to the interiorization stage	10
2	Correct until the coordination stage	30
3	Correct until the reversal stage	60
4	Correct up to the encapsulation stage	90
5	Correct up to the de-encapsulation stage	100

This research uses two types of validity, namely content and construct. Validity is the compatibility level between the measuring instrument and the one to be measured [23]. Two validators carried out content validation from each of the two private universities in Malang. The validation sheet questions contain material ratings/assessment, barrier indicators, and language with a rating scale of 1 to 4. The content validity was calculated using Aiken's V as follows [24],[25].

$$V = \sum(r - l) / [n(C - 1)]$$

r = score given by the assessor

l = lowest validity assessment score

C = highest validity assessment score

n = number of experts who made the assessment

This research involved four assessors and 4 rating scales. Aiken's V minimum standard for this research was 0.92, with a probability of 0.020 [24]. Construct validity is used to identify the validity and reliability of the questions. The data were calculated using SPSS 21.

3. Results and Analysis

Validity describes the extent of compatibility between the measuring instrument and the one to be measured. Content validity is a series of questions related to material, barrier indicators, and language. In comparison, construct validity is the relationship between the test score and the theoretical construct prediction.

3.1. Content Validity

Before being tested on pre-service teachers, the instrument questions had been arranged based on indicators of cognitive obstacles on negative fractions material. Four validators carried out the validation. This assessment was carried out to determine content validity. The content validity coefficient was calculated based on Aiken's V. The calculated result was declared as valid when fulfilling the Aiken's V coefficient limit for 4 rating

scales and four assessors, namely 0.92 with a probability of 0.020. Aiken's V average score can be seen in Table 4. below.

Table 4. Aiken's V average score for the scoring rubric

Validation	Average of Aiken's V
Material	0.96
Barrier indicator on the questions	0.94
Language	0.93

Some suggestions for improvement from the validators, namely the need to pay attention to the command sentence in question number 1 that used an exclamation mark and pay attention to the spelling of the language in the questions. Meanwhile, the other validators gave revisions related to the language in question 2.

3.2. Construct Validity

The validity and reliability of the questions using SPSS can be seen in Table 5. and Table 6. below.

Table 5. Result of question validation

Problem	Problem 1	Problem 2	Criteria
t count	4.71	3.76	valid
t table	1.99	1.99	valid

The questions are declared as valid if t count \geq t table. Based on Table 5., it is obtained that t count for question 1 is greater than t table for question 1, namely $4.71 > 1.99$, and t count for question 2 is greater than t table for question 2, namely $3.76 > 1.99$. It means that question 1 and question 2 can be declared as valid.

The result of the questions' reliability can be seen in Table 6. below.

Table 6. Reliability statistics

Cronbach's alpha	Cronbach's alpha based on standardized items	N of Items
.215	.262	3

Based on Table 6., it can be seen that $0.262 > 0.05$ so that the questions can be declared as reliable.

The result of the content validity shows a valid value because it fulfils Aiken's V coefficient. This means that the questions are appropriate and relevant to the objectives to be achieved. This research aims to develop and validate a negative fraction instrument to measure the cognitive obstacle of pre-

service mathematics teachers according to mental mechanism stages. The research's initial stage was carried out by analysing the pre-service teachers, the material, and the literature studies related to fraction material in college. According to the expert, the content is in the category of valid.

In this research, an instrument to measure cognitive obstacles to negative fractions learning material has been developed. At the same time, previous studies revealed only a cognitive obstacle to positive fractions learning material [9],[26],[16]. Other researches showed the cognitive obstacle to negative integers [1],[27].

In measuring the cognitive obstacle on negative fractions, mental mechanism stages from APOS were used. This is in line with another research that stated that APOS's mental mechanism stages could be used to analyse the understanding of pre-service teachers regarding fraction material [17]. APOS theory can also be used to analyse teaching on numbers of material in universities [19]. Also, the APOS theory can explore pre-service teachers' understanding of fraction material [18]. The experts' presentation explained why the process of pre-service teachers' obstacle on the problem of fractions could be analysed using the APOS theory.

This research results show a valid and reliable development instrument. However, the research has limitations as follows: (a) the small number of sample size, and (b) not using the triangulation process at the time the cognitive obstacle was arising in solving problems on negative numbers. Modification and revision are required for the instrument being developed.

Based on the statistical result, negative fraction questions that can measure the cognitive obstacle of pre-service mathematics teachers were found. Future researches are suggested to use triangulation related to the cognitive obstacle that arises when solving negative fraction questions.

4. Conclusion

The research findings show that negative fraction questions have a high level of validity. The questions can be used to measure the cognitive obstacle of pre-service teachers when solving fraction problems. Two questions instrument had been developed to measure the cognitive obstacle of pre-service mathematics teachers. The developed instrument can be applied in a learning process to measure the cognitive obstacle of pre-service mathematics teachers on fraction problems because it has high validity and reliability.

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