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Development of Rubric of Higher Order Thinking Skills Assessment on Mathematics Learning

ABSTRACT

This research aims to develop a rubric of Higher-Order Thinking Skills Assessment on mathematics learning that is valid, reliable, and practical. The Plomp's developmental method, the Generic model for educational design, was deployed to develop the HOTS assessment rubric. The method consisted of 4 phases namely; (1) preliminary investigation, (2) design, (3) develop, and (4) implementation and evaluation. The rubric was designed and developed to measure students' higher-order thinking skills in mathematics learning. The rubric was developed by integrating HOTS characteristics in mathematics, namely; critical thinking, problem-solving, mathematical understanding, mathematics modelling, proof and reasoning, mathematical representation, and mathematical communication. The HOTS assessment rubric's quality was examined using Plomp's product/prototype quality criteria: (1) validity; (2) reliability, and (3) practicality/usability. The rubric of the HOTS assessment was validated by 2 validators that are experts on HOTS in mathematics. The practicality/usability of the rubrics was examined by 5 mathematics teachers from different Junior High schools. The validity and reliability were measured using the Expert Agreement Index (EAI) from Gregory, while the rubric's practicality was analysed using practicality product criteria. The research shows that the validity of the rubric of HOTS assessment on mathematics learning is 0.82 (valid) and the reliability is 0.79 (reliable). Meanwhile, the practicality of the rubric is 81.02 (good). In conclusion, the rubric of the HOTS assessment on mathematics learning is valid, reliable, and practical to use to measured students' higher-order thinking skills in mathematics learning.

Keyword: *Rubric, HOTS, Assessment, Mathematics, Analysis, Evaluate, Create*

A. INTRODUCTION

Assessment of higher-order thinking skills is still challenging for mathematics teachers in Indonesia. A study found that 79% of elementary teachers have some obstacles in designing and implementing HOTS-based evaluation (Rapih & Sutaryadi, 2018). This is supported by many research that found teacher has difficulties to conducted a HOTS-oriented lesson plans and assessment format (Gradini, 2021; Jelatu et al., 2019; Retnawati et al., 2017; Sujadi et al., 2020). Thus, it is affecting students ability on solving HOTS problems (Gradini et al., 2018; Ichsan et al., 2019; Rahmawatiningrum et al., 2019; Sa'Dijah et al., 2020; Santoso et al., 2021). The HOTS content in textbooks and assessment tools is important and has a significant effect on students achievement (Pratama & Retnawati, 2018). A study showed that the test constructed by a majority of teachers does not measure the top-three level of Bloom Taxonomy, which is the higher-order thinking skill level (Abosalem, 2016). Therefore, Malik found that teachers need a ready-to-use assessment instrument at the HOTS level (Malik et al., 2015).

There are many terms that define Higher-Order Thinking Skills (HOTS). Higher and lower order thinking skills have been clearly described by many researchers and have become a trend in educational research in recent years (R. Collins, 2014; V. Collins, 2010; Conklin, 2012; Dewey & Bento, 2009; Ercikan & Seixas, 2020; Heong et al., 2011; Madhuri et al., 2012; Marshall & Horton, 2011; Marzano et al., 1988; Marzano & Kendall, 2007; Newmann, 1990; Preus, 2012; Yee et al., 2015). However, LOTS and HOTS have been initiated since 1956 by some educational experts through their critical thinking studies (Halpern, 1999; Miri et al., 2007; Resnick, 1987), the higher cognitive level of educational objectives (Anderson et al., 2001; Bloom et al., 1956; Marzano et al., 1988), creative thinking (Hyerle & Alper, 2013; Lewis et al., 2009), problem solving (Kruger, 2013).

This study relied on HOTS defined by (Brookhart, 2010) that used three terms in defining HOTS, namely; (1) HOTS is a transfer process, (2) HOTS is critical thinking, and (3) HOTS is problem-solving. Two of the most important educational objectives are to promote retention and transfer (which, when it happens, indicates significant learning). Students must remember what they have learned, whereas transfer necessitates not only remembering but also making sense of and being able to apply what they have learned (Anderson et al., 2001). In other words, HOTS as a transfer process in the context of learning is emerging meaningful learning, namely the ability of students to apply what students have learned into new situations with or without direction. As critical thinking, Brookhart retrieves the idea from (Norris & Ennis, 1989) that asserted critical thinking as a reasonable and reflective process. This is supported by a study that proposed critical thinking is essential in mathematics problem-solving skills (Peter, 2012). Meanwhile, in developing HOTS as problem-solving, Brookhart refers to (Brookhart & Nitko, 2011) and (Bransford et al., 2005). HOTS as a problem-solving is a process to make students able to solve real problems in real life, which are generally unique so that the completion procedures are also unique and not routine. Problem-solving is an activity that can help students hone and develop their Higher Order Thinking Skills (HOTS) in mathematics (Abdullah et al., 2015). Consequently, to assess HOTS in mathematics learning, the teacher has to examine the transfer process, critical thinking, and problem-solving skill.

This study aims to develop a rubric of Higher-Order Thinking Skills (HOTS) assessment on mathematics learning. The study on the assessment rubric of HOTS is still limited. The rubric of HOTS assessment is essential to develop since there is a high demand for teachers. There are numerous studies on the assessment of HOTS in mathematics, but limited to HOTS problems and test only. This study focused on the rubric to examine students higher-order thinking skills with the criteria for the developed rubrics are valid, reliable, and practical. The teacher also tends to evaluate students understanding on the three-bottom level of Bloom taxonomy (Abosalem, 2016) due to their lack of knowledge and access to an instrument of assessment (Ahmad et al., 2018). Therefore, it is important to develop a rubric that teachers are able to use to measure/ examine students Higher-Order Thinking Skills (HOTS) in the mathematics classroom.

Numerous studies have been conducted on the link between assessment and higher order thinking skills. Those studies shown increased student accomplishment has been linked to the use of tasks and exams that involve intellectual work and critical thinking. For examples, Pogrow developed a program that deploys HOTS for educationally disadvantaged kids; students with learning difficulties. The program focuses on four different types of thinking abilities: (1) metacognition, or the ability to think about thinking; (2) inferences; (3) transfer, or generalizing ideas across contexts; and (4) information synthesizing (Pogrow, 2005). Another studies found that metacognitive training and instruction; both domain-general and domain-specific characteristics, has improve children's performance in a variety of fields (Zohar & Barzilai, 2015). Like Pogrows' programme, The Mathematics Learning Discourse (MLD) project reported being able to foster higher order thinking and academic language in urban mathematics classrooms (Staples & Truxaw, 2010). Assessing HOTS is believed to increase students thinking skills, achievement, and motivation (Brookhart, 2010). Meanwhile, Widana et all found that HOTS assessment is effective to implemented to increase students critical thinking in mathematics (Widana et al., 2018). According to Ercikan and Seixas, developing assessments that provide meaningful information are essential (Ercikan & Seixas, 2020). Higgins, Hall, Baumfield and Moseley conducted a meta-analysis of studies on student cognitive, success and attitude interventions of thinking skills. They found that there is a strong effect of the implementation of higher order thinking skills as an approach on (1) verbal and non-verbal reasoning; (2)reading, mathematics, and science tests; (3) students' attitude and motivation (Higgins et al., 2005). Thus, student improvement in thinking, content area achievement and motivation can all be aided by thinking-skills interventions. To hone students' capability to analyze, evaluate, and create teachers have to choose an appropriate learning model, develop good material, and use an appropriate assessment (Rosidin et al., 2019). The programmes reported to assessed students' higher order thinking skill using a series of tests and rubrics.

Rubric has been popular as an assessment tool among teachers to examine student ability/skill. Andrade argues that rubrics can be used both as a teacher evaluation tool and student self-assessment (Andrade et al., 2010). Some studies support this opinion and show the effectiveness of rubric in mathematics learning evaluation and how it meets the rigorous standard (Boston, 2012; Danielson et al., 2014; Danielson & Marquez, 2016; Krause, 2010; Panadero & Romero, 2014). Since rubrics to assessing HOTS is limited, teacher need to develop their own rubric that appropriate to the students.

Generally, HOTS assessment measures the metacognitive dimension, not just measuring the factual, conceptual, or procedural dimensions. The metacognitive dimension describes the ability of students to connect several different concepts, interpret, problem-solving, deploy problem solving strategies, find new methods, reasoning, and make the right decisions. So that, in constructing assessment instrument on HOTS, teacher should consider following characteristics: (1) transfer of one concept to another; (2) process and apply information; (3) looking for links from different kinds of information; (4) use information to solve problems; and (5) critically examine ideas and information. In constructing the assessment of HOTS, Brookhart suggested following these principles, namely; (1) using introductory material that novel and allow students to gather information, and (2) managing the cognitive complexity and difficulty separately to overcome the misconception on level of difficulty and level of thinking.

B. METHODS

The Plomp's developmental method, the Generic model for educational design, was deployed to develop the HOTS assessment rubric. The method consisted of 4 phases namely; (1) preliminary investigation, (2) design, (3) realization, and (4) implementation and evaluation (Nieveen & Folmer, 2013; Tjeerd Plomp, 2000). The preliminary investigation conducted in five activities; front end analysis, student condition analysis, material analysis, task analysis, and specification of learning objectives. The important element in this phase is defining the problem. In the design phase, the blue-print of rubric designed by generating all the parts of the solution, comparing and evaluating the various alternatives then producing the best design choice of the rubrics. The rubric was designed and developed to measure students' higher-order thinking skills in mathematics learning. In realization phase, the rubric constructed using HOTS aspect defined by Brookhart as follow: (1) the top-three level of Blooms Taxonomy (analyse, evaluate, and create); (2) logical reasoning; (3) problem-solving; (Brookhart, 2010). The rubric also adapted a rubric on problem-solving (Kennedy High School, 2006). On implementation and evaluation phase, the HOTS assessment rubric's quality was examined using Akker's product/prototype quality criteria: (1) content validity, (2) reliability, and (3) practicality/usability (Nieveen & Folmer, 2013; Van De Akker et al., 2006).

The rubric was validated by 2 validators that are experts on HOTS in mathematics. If the validity coefficient is high (R > 75%), it can be stated that the HOTS rubric is valid. If this is not the case, it is necessary to make revisions based on suggestions from the validators or by reviewing aspects that have less value. Then it is re-validated and then re-analyzed until it meets the criteria. The content validity were measured using the interrater agreement of experts, as follows (Gregory, 2011):

Table 1. Interrater Agreement Model for Content Validity

		Expert Judge #1	
		Weak Relevance (item rated 1 or 2)	Strong Relevance (item rated 3 or 4)
Expert Judge #2	Weak Relevance (item rated 1 or 2)	A	B
	Strong Relevance (item rated 3 or 4)	C	D

$$Content\ validity = \frac{D}{(A+B+C+D)} \quad (1)$$

Thatcher states that reliability is the extent to which an experiment, test, or many measurement procedures produce the same results on repeated trials (Thatcher, 2010). Reliability measured by using Kuder-Richardson Formula 21(Brown, 2014) ,as follow:

$$r = \frac{K}{K-1}[1 - \frac{K*p(1-p)}{\sigma^2 x}] \quad (2)$$

Table 2. Criteria of Reliability Coefficient (University of South Florida, 2021)

Reliability Score	**Reliability Criteria**
$0.80 \le r \le 1.00$	Very Good Reliability
$0.50 \le r \le 0.79$	Good Reliability
$0.00 < r \le 0.49$	Not reliable

The practicality/usability of the rubrics was examined by 15 mathematics teachers from different Junior High schools. The practicality questionnaire consisted of 5 scale of Likert then analyzed using practicality product criteria.

Table 3. The Practicality Criteria of Product

Interval skor	**Kategori**
$x > \bar{x}_i + 1{,}8\ SB_i$	Very practical
$\bar{x}_i + 0.6SB_i < x < \bar{x}_i + 1{,}8\ SB_i$	Practical
$\bar{x}_i - 0.6SB_i < x < \bar{x}_i + 0{,}6\ SB_i$	Quite Practical
$\bar{x}_i - 1{,}8\ SBi < x < \bar{x}_i - 0{,}6\ SB_i$	Less Practical
$x \le \bar{x}_i - 1{,}8\ SB_i$	Not Practical

C. RESULT AND DISCUSSION

First aspect of the rubric is assessing student ability of analyse, evaluate, and create. Blooms is a commonly used taxonomy in Indonesia since its usefulness in categorizing the learning objectives and assessment into the level of cognitive. Student ability in analysis examined from their abilities to divide or structure information into smaller parts to identify patterns or relationships, to recognize and distinguish the causes and effects of a complex scenario, and to identify/formulate questions. Meanwhile the evaluation is examined from student ability to provide an assessment of solutions, ideas and methodologies using suitable criteria or existing standards to ensure their effectiveness or benefits, to make hypotheses, criticizing and testing, and to accept or reject a statement based on predetermined criteria. The creation level measured from student ability to make generalizations of an idea or perspective on something, to design a way to solve the problem, and to organize elements or parts into a new structure that has never existed before. The second aspect of the HOTS rubric is logical and reasoning. This is measured by students understanding in generating mathematical models, the quality of the mathematical model created, solution construction, conclusion drawn, and justification (judgement). The third aspect is problem solving. The aspect is measured by (1) students' understanding of the topics, (2) effective and appropriate problem-solving strategies, and produce correct answers, and (3) written mathematical communication. The students higher-order thinking measured by using 4 scale rating; exemplary (4), proficient (3), develop (2), and emerging (1). The important thing to note is teacher need not to use all the aspect of rubrics, but it depends on the level of complexity of the HOTS problem. In assessing the top-three level of Blooms, the rubrics used depend on the problems assigned to the cognitive level. Taxonomy The HOTS rubric that has been constructed described as follow:

Table 4. Rubric of Higher-Order Thinking Skills in Mathematics

HOTS Aspect	**Criteria**			
	Exemplary	**Proficient**	**Develop**	**Emerging**
	4	**3**	**2**	**1**
Mathematical understanding	Students have a clear and accurate understanding of material/ topic	Students have a functional understanding of the material/ topic	Students understand some of the material/ topic fairly	Students do not or have little understanding on the material/ topic
Analysis, evaluation, and creation level	Student answers are clear, complete, well explained, and accurately reflect knowledge of the topic.	Student answers are clear, complete, but not well explained, and do not accurately reflect knowledge of the topic.	Student answers are partially clear and accurate	Student answers are not clear, not accurate, and irrelevant
Logical and reasoning	Students have a clear and accurate understanding in producing accurate/correct mathematical models.	Students have adequate understanding in producing mathematical models that are mostly correct/accurate.	Students have partial understanding so that it shows some difficulties in making mathematical models.	Students show inaccurate and incomplete understanding and produce incomplete/inaccurate mathematical models
	The way in which the evidence supports the answer /premise/ thesis is clear, logical, and well explained.	The way in which the evidence supports the answer/premise/thesis is mostly clear and logical. Some explanation is given.	The way in which the evidence supports the answer/premise/thesis partially clear and logical, although some explanation is given.	The way in which the evidence supports the answer/premise/thesis is not clear and not logical. No explanation is given.
	Students create models to simplify complex situations and identify limitations of models	Students create models to simplify complex situations	Students create limited models to simplify complex situations	Students do not make mathematical models of the given problem
	Students construct logical, correct, complete solutions with justification and identify the	Students construct logical, correct, complete solutions with justification	Students provide partially correct solutions with justification or correct solutions without	Students provide partially correct or incorrect solutions without justification

HOTS Aspect	Criteria			
	Exemplary	Proficient	Develop	Emerging
	4	3	2	1
	source of the error.		logical steps	
Problem-solving	Students analyse all the information; constraints, objectives, definitions, and implied assumptions given to mathematical problems	Students analyse most of the information; constraints, objectives, and definitions given to mathematical problems	Students analyse a small amount of information; constraints and/or objectives, given to mathematical problems	Students ignore the information given to mathematical problems
	Students use/ implement effective and appropriate problem-solving strategies, and produce correct answers.	Students use/ implement correct problem-solving strategies. However, there are strategies that are not needed or are not necessary, even though they produce the right answer.	Students use/ implement problem-solving strategies that result partially incorrect answers.	(i) Students do not use/ implement clear or correct problem-solving strategies; or (ii) all student answers are wrong; or (iii) student does not solve the problem/question.
Mathematical Communication (written)	Students use correct or appropriate mathematical and language terms to communicate their answers.	Students use mathematical terms and language that are correct or appropriate to communicate their answers.	Students provide misleading and confusing explanations to communicate their answers.	Students provide incomplete and/or inaccurate explanations.
	Students use clear and accurate mathematical representations to explain their answers.	Students use the correct mathematical representation to explain the answer.	Students use mathematical representations that are partially correct.	Students use incorrect or incomplete mathematical representations.

Table 5. Interrater Agreement of Validity of HOTS Rubric – validity 1

		Expert Judge #1	
		Weak Relevance (Item rated 1 or 2)	Strong Relevance (Item rated 3 or 4)
Expert Judge #2	Weak Relevance (item rated 1 or 2)	2	1
	Strong Relevance (item rated 3 or 4)	1	12

The first validation show that the product has a validity coefficient of 0.706 with a reliability of 0.809. If the coefficient of validity is high (RVI > 75%) then it can be stated that the rubric is valid. Despite the reliability is very reliable, the first prototype of HOTS rubric in mathematics is not valid, yet, it need revision and then validated again. After did some revision, 2 judges were asked to validated the rubric. The result shown at table 6.

Table 6. Interrater Agreement of Validity of HOTS Rubric – validity 2

		Expert Judge #1	
		Weak Relevance (Item rated 1 or 2)	Strong Relevance (Item rated 3 or 4)
Expert Judge #2	Weak Relevance (item rated 1 or 2)	0	3
	Strong Relevance (item rated 3 or 4)	0	13

The second validation show that the product has a validity coefficient of 0.81 with a reliability of 0.89. Since the coefficient of validity is high (RVI > 75%) and the reliability is also high, then it can be stated that the HOTS rubric in mathematics is valid and reliable.

The practicality measurement is described based on the product practicality classification formula, where the assessment for the practicality of product development consists of 18 question items with a rating scale consisting of 5 categories, namely Very Good (5), Good (4), Fair (3), Poor (2), and Bad (1). By applying the practicality criteria of product on table 3, the practicality criteria of the rubric shown at table 7.

Table 7. Practicality Criteria of The Rubric

Score Interval	Category
$x > 75,6$	Very practical
$61,2 < x \leq 75,6$	Practical
$46,8 < x \leq 61,2$	Quite Practical
$32,4 < x \leq 46,8$	Less Practical
$x \leq 32,4$	Not Practical

The practicality of rubric score is 75.08. Thus, the HOTS rubric in mathematics is practical. Furthermore, the rubric of Higher-Order Thinking Skills (HOTS) is valid, reliable, and practical to deploy in mathematics learning.

During the trial, respondents positive and negative comments that used as a revision. They made positive comments in overall “user friendliness”. They made negative comments in the construction of the rubric, such as it need to reduce some wordiness and bolding the word that shows the score. However, the respondents still confusing the scientific terms regarding mathematical reasoning and representation. Mostly, they did not understand the "justification", "representation", and "mathematical model" term. This problem solved by given the definition of each mathematical terms bellow the rubrics. The respondents and validators also suggest that the rubric is one-page format, including the column for scoring, and the conversion score of student higher-order thinking skills. Therefore, the revision made to make the rubric easier to use. The final version of the HOTS rubric in mathematics shown as follow.

Rubric of Higher-Order Thinking Skills in Mathematics

Students' Name: ____________ Class : ____________ HOTS Problem : ____________ Date : ____________

HOTS Aspect	Exemplary	Proficient	Develop	Emerging	Score
	4	3	2	1	
Mathematical understanding	Students have a clear and accurate understanding of material/ topic	Students have a functional understanding of the material/ topic	Students understand some of the material/ topic fairly	Students do not or have little understanding on the material/ topic	
Analysis, evaluation, and creation level	Student answers are clear, complete, well explained, and accurately reflect knowledge of the topic.	Student answers are clear, complete, but not well explained, and do not accurately reflect knowledge of the topic.	Student answers are partially clear and accurate	Student answers are not clear, not accurate, and irrelevant	
Logical and reasoning	Students have a clear and accurate understanding in producing accurate/correct mathematical models.	Students have adequate understanding in producing mathematical models that are mostly correct/accurate.	Students have partial understanding so that it shows some difficulties in making mathematical models.	Students show inaccurate and incomplete understanding and produce incomplete/inaccurate mathematical models	
	The way in which the evidence supports the answer /premise/ thesis is clear, logical, and well explained.	The way in which the evidence supports the answer /premise/thesis is mostly clear and logical. Some explanation is given.	The way in which the evidence supports the answer/ premise/thesis is partially clear and logical, although some explanation is given.	The way in which the evidence supports the answer/ premise/thesis is not clear and not logical. No explanation is given.	
	Students create models to simplify complex situations and identify limitations of models	Students create models to simplify complex situations	Students create limited models to simplify complex situations	Students do not make mathematical models of the given problem	
	Students construct logical, correct, complete solutions with justification and identify the source of the error.	Students construct logical, correct, complete solutions with justification	Students provide partially correct solutions with justification or correct solutions without logical steps	Students provide partially correct or incorrect solutions without justification	
Problem-solving	Students analyse all the information; constraints, objectives, definitions, and implied assumptions given to mathematical problems	Students analyse most of the information; constraints, objectives, and definitions given to mathematical problems	Students analyse a small amount of information; constraints and/or objectives, given to mathematical problems	Students ignore the information given to mathematical problems	
	Students use/ implement effective and appropriate problem-solving strategies, and produce correct answers.	Students use/ implement correct problem-solving strategies. However, there are strategies that are not needed or are not necessary, even though they produce the right answer.	Students use/ implement problem-solving strategies that result partially incorrect answers.	(i) Students do not use/ implement clear or correct problem-solving strategies; or (ii) all student answers are wrong; (iii) student does not solve the problem/question.	
Mathematical Communication (written)	Students use correct or appropriate mathematical and language terms to communicate their answers.	Students use mathematical terms and language that are correct or appropriate to communicate their answers.	Students provide misleading and confusing explanations to communicate their answers.	Students provide incomplete and/or inaccurate explanations.	
	Students use clear and accurate mathematical representations to explain their answers.	Students use the correct mathematical representation to explain the answer.	Students use mathematical representations that are partially correct.	Students use incorrect or incomplete mathematical representations.	

Figure 1. The Final version of Rubric of Higher-Order Thinking Skills in Mathematics

The score of each aspect then sum-up to gain student total score. The average of score then calculated and converted to measure student higher-order thinking skill as follow category:

Table 8. The HOTS Level Category

Score Interval	HOTS Level
$3.50 < x \leq 4.00$	*Exemplary*
$3.00 < x \leq 3.50$	*Proficient*
$2.50 < x \leq 3.00$	*Develop*
$1.00 \leq x \leq 2.50$	*Emerging*

D. CONCLUSION AND SUGGESTIONS

The rubric of Higher-Order Thinking Skills (HOTS) is valid, reliable, and practical to use in assessing students HOTS in mathematics learning. The validity coefficient is 0.81 (high validity), reliability coefficient is 0.89 (very reliable), and the practicality score is 75.08 (practical). The final version of the rubrics ready to presented to bigger group of mathematics teacher to gain some feedbacks. The teacher feedback is valuable to refine the rubrics. However, the rubric need to be trialed to measure its effectiveness in assessing the student higher order thinking skills. Future research on HOTS rubric is also needed to see teacher's acceptance and the usefulness of the rubric.

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Possessive Review the rules for possessive nouns.

Possessive Review the rules for possessive nouns.

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P/V You have used the passive voice in this sentence. You may want to revise it using the active voice.

P/V You have used the passive voice in this sentence. You may want to revise it using the active voice.

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Proofread This part of the sentence contains an error or misspelling that makes your meaning unclear.

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Article Error You may need to use an article before this word. Consider using the article **the**.

Possessive Review the rules for possessive nouns.

PAGE 4

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Possessive Review the rules for possessive nouns.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

S/V This subject and verb may not agree. Proofread the sentence to make sure the subject agrees with the verb.

Sp. This word is misspelled. Use a dictionary or spellchecker when you proofread your work.

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