Volume 5, Number 2, June 2024
Journal of Research on Mathematics Instruction
DOI: https://doi.org/10.33578/jrmi.v5i2.98
Journal's Webpage: http://jrmi.ejournal.unri.ac.id

Development of Mathematics Tests for Higher Order Thinking Skills on Quadratic Equations and Functions

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ARTICLE'S INFORMATION

Article history:

Received: Jun-28-2024

Reviewed: Jul-04-2024

Accepted: Jul-20-2024

Keywords: HOTS, Quadratic Equation, Quadratic Function, Test

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ABSTRACT

This research aims to produce valid and reliable phase E mathematics higher-order thinking Skills (HOTS) questions on quadratic equations and functions. The research conducted by researchers in development research with the development model used, namely the type of development studies with two stages, namely preliminary and formative evaluation. The subjects of this study were students of class X SMAN 2 Karimun. In this study, the average score of the assessment of the three aspects (material, construct, and language) by the three validators was 86.16%, with a very valid category. In contrast, the average of all statements in the student response questionnaire was 88.33% with very good criteria and had a reliability value of 0.89 with a high category. This study concluded that the resulting 22 questions of Higher Order Thinking Skills (HOTS) mathematics phase E on the material of equations and quadratic functions developed have met the valid and reliable criteria.

INTRODUCTION

In 21st-century life, technology has entered various aspects of life. It is considered essential to improve the quality of human resources to face the challenges of the global era and be competitive [1]. Facing the 21st century, students must be equipped with various abilities [2]. According to BSNP (National Education Standards Agency), technological advances have an important position in various disciplines or advance the way of thinking of each individual based on mathematics as an educational science that has a good or bad influence on a country, including Indonesia [3]. Mathematics is an important science in everyday life. It is structured, organized, interrelated, and tied between one material and another [4]. Therefore, mathematics is one of the most important sciences in technological advancement in the 21st century. In its development, mathematics always demands improvement on every side. If previously learning mathematics only required understanding, having higher-order thinking skills (HOTS) is necessary.

TIMSS and PISA results among students in Indonesia are low because students in Indonesia are not accustomed to working on questions with high-level thinking or HOTS [5]. High-level thinking skills, or HOTS, are a student's thinking process at a higher cognitive level. At this level, students are not only required to understand the concepts but can also apply them to solve the problems given [6].

Based on Bloom's revised taxonomy, higher-order thinking skills (HOTS) include cognitive levels C4 (analyze), C5 (evaluate), and C6 (create). The level of analyzing can be seen when students can decompose a concept into various parts, evaluating can be seen when students provide an assessment evaluation of a thing or phenomenon that occurs, and creating when students can unite elements in a new pattern by generating, planning, and producing [7].

Equations and quadratic functions are materials in the algebraic element, which are still rare in the work. Students are given questions with HOTS type [8]. Not a few students also revealed that they had difficulty when solving problems and solving math problems, especially in quadratic function material, while the quadratic function is one of the materials that can hone students' higher-level thinking skills as well as one of the materials for prerequisite preparation for learning higher-level material.

HOTS questions are characterized as follows.

1. Measuring higher-order thinking skills

The Australian Council for Education Research (ACER) defines higher-order thinking skills as analyzing, presenting arguments or reasons, applying concepts to different situations, composing, and creating. The high-level thinking skills referred to in this study are the ability to analyze, evaluate, and create, which are at the C4-C6 cognitive level.

2. Divergent

Divergent means that HOTS questions allow students to provide different answers according to their thinking process and perspective because they measure analytical, critical, and creative thinking processes that tend to be unique or different responses for each individual. Therefore, to support the divergent nature of HOTS questions, the questions developed are in the form of descriptions that allow students to have different ways of solving.

3. Using Multirepresentation

HOTS questions generally do not present all information explicitly but force students to explore the implicit information in the question themselves. To fulfill this expectation, the HOTS questions that will be developed in this study use representations such as verbal in the form of sentences, visual in the form of pictures or graphs, and symbolic and mathematical in the form of numbers, formulas, or equations.

4. Based on contextual problems

HOTS problems that are based on real situations in everyday life require students to be able to apply the concepts learned in class to solve problems. Preparing HOTS questions generally uses a stimulus as the basis for making questions. The stimulus can be sourced from global issues such as information technology, science, economics, health, education, and infrastructure. Stimuli can also be taken from topics related to the education unit, such as culture, customs, cases in the region, or various advantages found in certain regions.

The steps in developing HOTS questions are a) determining learning outcomes and learning materials, b) compiling the flow of learning objectives, c) compiling question grids, d) formulating question indicators, and e) writing questions according to the rules of question writing. In designing HOTS questions, there needs to be standardization to determine the quality of the questions. Good questions go through a standardization process, namely the validity and reliability process, so the questions are valid and reliable for certain purposes.

This study aims to produce valid and reliable mathematics higher-order thinking Skills (HOTS) questions in phase E on equations and quadratic functions. Based on the problems described above regarding higher-order thinking skills, the researcher decided to conduct a study entitled the development of Mathematics Higher Order Thinking Skills (HOTS) questions on equations and quadratic functions. The material on quadratic equations and quadratic functions was developed, referring to the learning outcomes of the independent curriculum phase E, namely being able to use quadratic equations and quadratic functions in solving problems. The HOTS questions developed are HOTS questions based on Bloom's cognitive levels revised by Anderson and Karthwhol, namely C4 (analyzing), C5 (evaluating), and C6 (creating).

METHODS

The research conducted by researchers in development research with the development model used, namely the type of development studies with two stages, namely preliminary and formative evaluation. The formative evaluation stage adopts the steps by Tessmer, which consists of the stages of self-evaluation, expert review, one-on-one, small group, and field test. The development studies type is said to be appropriate for developing HOTS questions because this type aims to establish principles, designs, and products for practical field purposes [9].

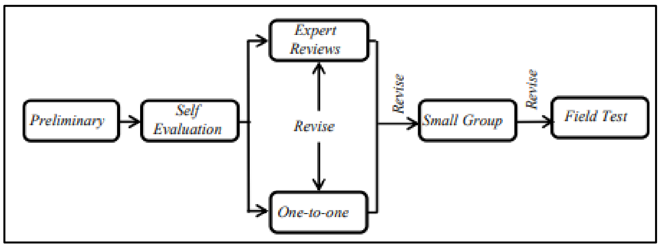

Figure 1. Stages of the Development Model

The data obtained from this study are qualitative data in the form of statements or words about the quality of an object and quantitative data to show the quality of the HOTS questions to be developed obtained from the results of the validator's assessment in the aspect of internal validity of HOTS questions and data from product trial results to assess item validation and reliability of HOTS questions, as well as the differentiating power and difficulty level of HOTS questions developed. The research instruments used to obtain data in this study are validation sheets, student response questionnaires, and HOTS question tests. The data collection techniques in this study are interviews, questionnaires, and tests.

a. Analysis of Internal Validation of HOTS Questions

To determine the validity of the HOTS questions developed, the results of the student answer scores obtained were tabulated and then analyzed using the following formula and information.

$$V_a = \frac{T_{sa}}{T_{sh}} \times 100\%$$

Description:

V_a = validation scorer

T_{sa} = Total empirical score from experts

T_{sh} = Total maximum expected score

Table 1. Internal Validity Criteria

Percentage	Description
$0 < V_a \leq 20$	Invalid
$20 < V_a \leq 40$	Less valid
$40 < V_a \leq 60$	Valid Enough
$60 < V_a \leq 80$	Valid
$80 < V_a \leq 100$	Very Valid

b. Analysis of Student Response Questionnaire

The results of student responses to the questionnaire collected were then tabulated and analyzed using the following formula.

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

Description:

V_p = Responden's score

T_{sp} = Total empirical score from respondents

T_{sh} = Total maximum expected score

Table 2. Student Response Criteria

Percentage	Description
0 – 20	Not very good
21 – 40	Not good
41 – 60	Good enough
61 – 80	Good
81 – 100	Very good

c. Validity Analysis of HOTS Problem Items

The validity of the HOTS items was obtained by testing the items developed for the research test subjects. The answers of the test subjects were then analyzed to determine the validity of the items. The analysis of the validity of the developed HOTS items was tabulated using the following formula.

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

Description:

r_{xy} = Correlation coefficient

X = Item score of the question item

Y = Number of scores per question

n = Number of respondents

$$t_{count} = r_{xy}\sqrt{\frac{n-2}{1-r_{xy}^2}}$$

Description:

Search t_{table} with $t_{table} = t_\alpha(dk = n-2)$

If $t_{count} > t_{table}$, the question HOTS item is valid, atau

If $t_{count} \leq t_{table}$, the question HOTS item is invalid.

d. Reliability of HOTS Questions

The reliability of the HOTS questions was obtained by testing the developed items on the research test subjects once and then analyzing them. The questions analyzed for reliability were declared valid, both internal and item validation. The score obtained from the completion of each student is calculated using Crobanch's alpha formula. The total variance of each item score is calculated as follows:

$$\sigma_t^2 = \frac{\sum X_i^2 - \frac{(\sum X_i)^2}{n}}{n}$$

Description:
σ_t^2 = The variance of each item's score
X_i = Item score of the i-th item
n = Number of test sources

$$\sigma_t^2 = \frac{\sum Y^2 - \frac{(\sum Y)^2}{n}}{n}$$

Description:
σ_t^2 = Total variance
Y = Total score of each question
n = Number of trial subjects

The reliability value of HOTS questions is determined using Cronbach's Alpha (α) formula.

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

Description:
r = Internal reliability of the whole instrument
k = Number of questions
$\sum \sigma_i^2$ = Sum of the variances of the scores of each item
σ_t^2 = Total variance

The reliability results obtained match the reliability assessment criteria in Table 3 below.

Table 3. Reliability Criteria

Percentage	Description
$0,00 < r \leq 0,20$	Very low
$0,20 < r \leq 0,40$	Low
$0,40 < r \leq 0,60$	Enough
$0,60 < r \leq 0,80$	High
$0,80 < r \leq 1,00$	Very high

RESULTS AND DISCUSSION

The development research that has been carried out produces a product in the form of E-phase math HOTS questions on quadratic equations and functions. The development model used in this research is the development studies type with two stages, namely preliminary and formative evaluation by Tessmer, which consists of self-evaluation, expert review, one-to-one, small group, and field test [10].

1. Preliminary Stage

In the preliminary stage, researchers designed and designed research products consisting of question grids, HOTS questions, alternative solutions, scoring guidelines, validation sheets, and student response questionnaires used in developing products. The HOTS questions developed at the design stage consisted of 27 description questions with 12 questions at the C4 (analyze) level, 11 questions at the C5 (evaluate) level, and four questions at the C6 (create) level. The questions developed are equipped with alternative solutions and holistic scoring guidelines adjusted to higher-order thinking indicators. The questions developed are used as a question bank that teachers can use as a reference in learning or as a learning resource for students in practicing higher-order thinking skills.

The results of the analysis conducted by researchers are as follows.

a. Analysis
   1) Needs Analysis: Needs analysis aims to identify, focus, and analyze fundamental problems related to students' higher-order thinking skills. The needs analysis was done by reviewing relevant literature and interviews with mathematics teachers. Based on the interview, it was found that currently, the questions used are still dominated by the level of lower-order thinking skills (LOTS), namely remembering (C1), understanding (C2), and applying (C3). One of the reasons is that the preparation of HOTS questions is not an easy thing.
   2) Student Analysis: Students used as test subjects studied quadratic equations and function material.
   3) Curriculum Analysis: following the independent curriculum of phase E of the Algebra element on the material of quadratic equations and functions.

b. Design Stage:
   1) Formulate HOTS question grids
   2) Determine the number and type of HOTS questions
   3) Formulate HOTS questions
   4) Determine alternative solutions and scoring guidelines for HOTS questions
   5) Designing research instruments through internal validation sheets and student response questionnaires.

2. Formative Evaluation Stage

a. Self-evaluation

At the self-evaluation stage, researchers and supervisors reassessed the initial product and research instruments developed. At this stage, the researchers and supervisors ensured that each product component was included to assess the assessment aspects on the validation sheet. The results of the assessment with the supervisor obtained 27 HOTS questions consisting of 12 questions at level C4 (analyze), 11 questions at level C5 (evaluate), and four questions at level C6 (create), which were approved to continue at the validation stage. Furthermore, this initial product is called prototype I.

b. Expert review

At the expert review stage, the developed prototype was internally validated. Internal validation was conducted by a team of validators on HOTS questions or prototype I with validated aspects, including material, construct, and language aspects. Validation was carried out by providing the validators with the question grids, HOTS questions, alternative solutions, scoring guidelines, validation sheets, and validation sheet scoring rubrics. Qualitative data is in the form of suggestions for improvement based on the results of the review conducted by the validator. Researchers used the suggestions from the validators to revise prototype I so that prototype II was produced. A recap of the average scores of the three aspects (material, construct, and language) of the developed HOTS questions assessed by the three validators can be seen in the following table.

Table 4. Calculation Results of Material, Construct, and Language Aspect Validation

	Aspects			**Category**
	Material	**Construct**	**Language**	
Total Score	116.61	113.50	118.83	
Average	4.32	4.20	4.40	
Percentage	86.38%	84.07%	88.02%	
(%) Total Validation	86.16%			Very Valid

c. One-to-one. The one-to-one stage was conducted together with the expert review stage. In the one-to-one stage, the prototype I was tested on three students of grade X SMA. The HOTS questions were tested at this stage to obtain assessments or comments from students regarding the readability of the HOTS questions developed. After the HOTS questions, direct interviews or discussions were conducted with three students in the one-to-one stage to obtain suggestions and comments after working on HOTS questions.

d. Small group. In the small group stage, prototype II was tested on 4 grade X students. Students were asked to work on HOTS-type questions for 120 minutes and then asked to fill out a student response questionnaire to obtain comments and suggestions on the questions that have been done. Overall, from the analysis sheet of students' answers, it can be seen that some students can understand the problem well and make relevant solution strategies so that the final result is obtained. There are some problems that students have been unable to solve correctly, and there are some errors in analyzing and performing calculations and interpreting the problem. In processing the response questionnaire data to students at the small group stage, the average percentage of all statements was 88.33% with very good criteria, so it can be interpreted that students responded positively to the HOTS questions developed.

e. Field test. The results of the revision of prototype II then referred to as prototype III, were tested on the research test subjects, namely class X students of SMAN 2 Karimun, which consisted of 31 students. Student answers were tabulated and analyzed for item validity and reliability.

1) Test of Question Item Validity

The item 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 formula. Next, t_{count} value of each item was compared with the t_{table} value = $t_{\propto}$ (df = n-2) and a significance level of 5%. The results of the validity test for each item can be seen in Table 5. below.

Table 5. Item Validity Test Results

Number of Questions	t_{count}	Description	Number of Questions	t_{count}	Description
1	0,87	Invalid	15	3,82	Valid
2	1,03	Invalid	16	4,72	Valid
3	1,71	Invalid	17	2,49	Valid
4	0,86	Invalid	18	3,69	Valid
5	0,94	Invalid	19	2,69	Valid
6	4,31	Valid	20	4,34	Valid
7	3,93	Valid	21	2,20	Valid
8	2,95	Valid	22	2,87	Valid
9	5,13	Valid	23	2,07	Valid
10	2,28	Valid	24	2,23	Valid
11	7,86	Valid	25	2,82	Valid
12	4,24	Valid	26	2,32	Valid
13	2,05	Valid	27	2,82	Valid
14	2,95	Valid			

The item is said to be valid if $t_{count} > t_{table}$, and invalid if $t_{count} < t_{table}$. The results of the validity test of 27 HOTS items developed with $t_{table} = t_{\propto}(31-2) = 2.045230$, 22 questions were categorized as valid, and five questions were categorized as invalid, namely question numbers 1, 2, 3, 4, and 5.

2) Reliability Test

The reliability test was conducted using Cronbach's Alpha formula. The HOTS questions included in the reliability test are considered valid in the item validity test. So, six HOTS questions with question numbers 1, 2, 3, 4, and 5 are not included because they are in the invalid category. The reliability test value obtained for 22 HOTS questions is 0.89, included in the high category.

In the formative evaluation stage, researchers carry out four stages to produce the final HOTS questions: the self-evaluation stage, expert review, one-to-one, small group, and field test. In the self-evaluation stage, further assessment of the products and assessment instruments developed by the researcher and the supervisor was carried out. 27 HOTS questions consisting of 12 questions at level C4 (analyzing), 11 questions at level C5 (evaluating), and four questions at level C6 (creating) were approved for validation.

At the expert review stage, the HOTS questions developed were validated by two mathematics education lecturers and one mathematics teacher covering aspects of material, construction, and language to obtain the internal validity of the product developed. Each aspect assessed by the validators has different assessment components. The differences are described through a validation sheet rubric that presents each research component's assessment criteria or descriptors as a benchmark for scoring. Based on the assessment results from the three validators, the average for the language aspect was 86.38% with a very valid category, the construct aspect was 84.07% with a very valid category, and the language aspect was 88.02% with a very valid category.

Along with the expert review, the prototype I was tested with three students in the one-to-one stage. After the working time was completed, the researcher conducted an unstructured interview with the students to obtain suggestions and comments on the HOTS questions, including writing improvements, adding pictures to the questions, and the time given in working on HOTS questions.

CONCLUSIONS AND SUGGESTIONS

Based on the results of the research and discussion, it can be concluded that 22 questions of Higher Order Thinking Skills (HOTS) mathematics phase E on equations and quadratic functions material developed using the development studies type research model consisting of preliminary and formative evaluation stages by Tessmer have met the valid and reliable criteria.

The obstacles or shortcomings faced at the field test stage are due to limited time and the availability of schools to conduct research. Researchers use a hybrid system, which they are better off doing directly (offline). Some recommendations that researchers can convey in connection with this research to develop Mathematics Assessment Instruments are as follows.

First, the assessment instrument in the form of phase E mathematics Higher Order Thinking Skills (HOTS) questions on quadratic equations and functions material developed has met the valid and reliable criteria. It has a good level of difficulty and differentiating power so that it can be used as an alternative assessment instrument or as a source of reference in developing HOTS questions for teachers to use during the learning process and as a source for students in practicing their high-level thinking skills.

Second, based on the results of item validation, five questions were obtained with invalid categories, namely numbers 1, 2, 3, 4, and 5. Researchers recommend that future researchers redevelop the five invalid questions to become valid.

Third, the HOTS questions are still dominated by C4-level questions. So, other researchers conducting similar research can explore questions at the C5 and C6 levels.

Fourth, at the formative evaluation stage, researchers did not follow the stages due to limited time and human resources. So, other researchers who will conduct similar research can follow the stages that should be beyond the limitations of time and human resources.

Fifth, during the field test stage, the researchers conducted the HOTS question test in one day, which was ineffective. For this reason, the researcher recommends that the next researcher conduct the test for two days to provide optimal results.

Researchers' limited knowledge and ability to develop HOTS questions and the stages that are not carried out according to the stages should be the cause of the deficiencies. In the future, other researchers who want to develop HOTS questions should better understand each step and learn more about developing HOTS questions. This is to produce quality HOTS questions to assess and improve students' higher-order thinking skills.

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