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Development of Mathematical Reasoning Ability Test Questions on the Topic of Exponential Functions and Quadratic Functions

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A B S T R A C T

Mathematical Reasoning Ability (KPM) is an important ability for students to be able to think logically and draw conclusions related to mathematics. This research aims to develop KPM test questions on exponential functions and quadratic functions. This type of research is Research and Development research with a development study approach which includes preliminary stages and formative evaluation. The formative evaluation stage was adapted from Tessmer, consisting of self-evaluation, expert review, face-to-face, small groups and field tests. The test subjects for this research were students in class XI-6 of SMA Negeri 1 Pekanbaru. Based on the results of the field tests, it was obtained: (1) 15 KPM test questions on exponential functions and quadratic functions which were declared externally valid; (2) the KPM test questions have a reliability value of 0.81 which is categorized as very high; (3) KPM test questions have an average level of difficulty of 0.40 in the "medium" category; and (4) the KPM test questions have an average differentiating power value of 0.44 in the "good" category.

1. Introduction

Reasoning is a thinking process in drawing conclusions based on certain rules. According to Sinaga (2016), reasoning is a process or activity of thinking that is used to draw conclusions by referring to certain facts and rules. Hendriana et al. (2021) added that reasoning is also an activity of thinking logically. In the context of learning mathematics, reasoning is very important because it helps students understand and find solutions based on established rules. The reasoning process in learning mathematics cannot be separated, because reasoning can be honed through the study of mathematics, and mathematical understanding can be obtained through the reasoning process.

Mathematical Reasoning Ability (KPM) is a thinking process used to reach logical conclusions in proving a statement to find solutions to mathematical problems (Astuti & Ristontowi, 2022). Santosa et al, (2020) stated that KPM is

the ability to understand mathematical concepts in a logical way, so that someone can draw conclusions or provide assessments. Mathematical reasoning supports students in analyzing mathematical conditions, by utilizing appropriate patterns and relationships and following regular steps, students can formulate valid arguments and draw rational conclusions (Nuriadin et al., 2021). According to the Decree of the Head of the Education Assessment Curriculum Standards Agency (BSKAP) Number 033/H/KR/2022, the purpose of learning mathematics in the independent curriculum is so that students can develop their abilities in applying reasoning related to patterns and properties, carrying out mathematical manipulations to produce generalizations, compiling evidence and explaining mathematical concepts and statements. According to the association of mathematics teachers in the United States known as the National Council of Teachers of Mathematics (NCTM), it explains that KPM is one of the important abilities for students to have (Ariati & Juandi, 2022). In addition, KPM is very much needed in the National Selection Based on Tests (SNBT) in accepting new students. One of the aspects measured in the SNBT pathway to enter college is mathematical reasoning (Ministry of Education and Culture, 2022). Thus, KPM needs to be trained and improved so that students can develop their knowledge in mathematics learning optimally.

Based on the explanation regarding the importance of KPM for students, several studies have found that KPM in students is still categorized as low. In a study conducted by Vebrian et.al (2021), it was explained that grade X students of Pangkal Pinang High School had a very low level of mastery of mathematical reasoning in each indicator. This is evidenced by their level of mastery of the indicators of manipulating mathematics, providing conjectures, evidence or reasons with a percentage of 42.88% and the ability to draw conclusions of 41.36%. In addition, the low KPM for students was also explained in the study of Efendi et al. (2024) that the KPM of grade XI students of SMA Negeri Plus Riau Province was relatively low, as can be seen from the average percentage of student scores in completing the KPM test which only reached 42.67%. This problem arises because students have difficulty answering questions, especially those related to the indicator of drawing conclusions logically and in general form. Based on the results of these studies, it shows that KPM among students is relatively low.

The low KPM in participants is due to the lack of educators in training and accustoming students to solving KPM questions. This is explained by Ahmad et al, (2018) in their research that teachers do not encourage students to reason independently, this can be seen from teachers who always guide students in solving questions, and the level of difficulty of the questions given to students is also relatively easy and moderate, so that it does not train students' reasoning. According to Vebrian et al, (2021) the KPM level in students is low because students are not used to solving reasoning questions routinely, this is caused by teachers who pay more attention to student learning outcomes by relying on limited abilities. A teacher needs to have high mathematical and pedagogical competencies in order to effectively help students improve KPM (Wijaya et al, 2021). In the learning process, teachers should train students with questions that

can develop KPM (Nursalam et al., 2017). Thus, efforts to improve the KPM must start from changing the teaching approach that is more supportive of students in learning, such as providing more varied challenges. In addition, it is also important for teachers to develop or take questions that can stimulate KPM in students. The reason teachers do not provide mathematical reasoning test questions to students is the lack of availability of references for the form of test questions with KPM (Putri & Destania, 2020). Although questions with mathematical reasoning are found in teacher reading materials, these questions have not been tested for validity, reliability, distinguishing power and level of difficulty. So regarding this matter, teachers really need references for KPM questions that are valid both internally and externally, have good reliability values, distinguishing power and level of difficulty. In addition, there has been no research that specifically discusses the development of KPM test questions on the topic of exponential functions and quadratic functions, especially in Pekanbaru. Thus, the purpose of this study is to produce KPM test questions on the topic of exponential functions and quadratic functions.

2. Methodology

his research is a Research and Development study with a development studies approach. This research was conducted at SMA Negeri 1 Pekanbaru Class XI-6. The research process includes two stages, namely the preliminary stage and the formative evaluation stage. The formative evaluation stages include self-evaluation, expert review, one to one, small group, and field test (Tessmer in Dewi & Syofiana, 2020). The following is a product development flowchart.

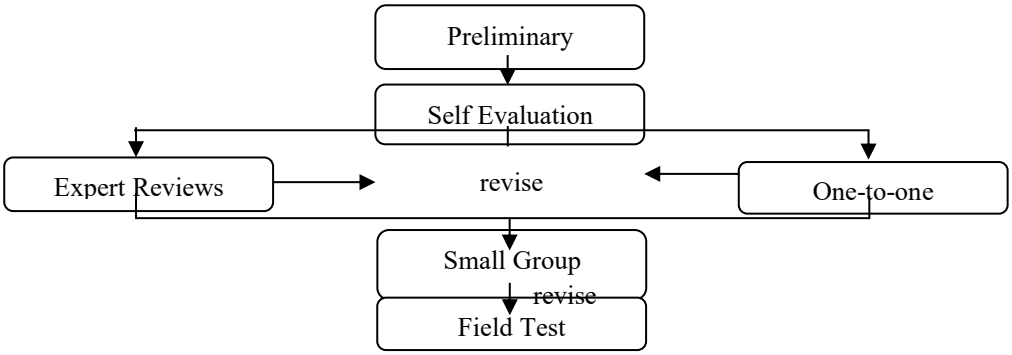


Figure 1. Product Development Flowchart

The types of data in this study consist of qualitative data and quantitative data. Qualitative data were obtained through input and comments from validators and students. Meanwhile, quantitative data were obtained from the assessment of validation sheets by validators and the results of product trials on students at the field test stage. Data analysis used in this study includes internal validity analysis, external validity analysis, reliability analysis, discriminatory power analysis, and analysis of the level of difficulty of the developed test instrument product.

3. Results and Discussion

This study produces test questions with Mathematical Reasoning Ability (KPM) indicators on the material of exponential functions and quadratic functions. The results of this study go through several stages, namely as follows.

Preliminary Stage

At this stage, it produces the analysis needed in the research and the design of the developed test questions. The analysis carried out produces:

a. Needs analysis
   The needs analysis resulted that mathematical reasoning ability is indeed very important for students to have. However, from the results of interviews conducted by 3 mathematics teachers in three schools, it was stated that students were not yet accustomed to working on questions with reasoning ability. In addition, teachers had quite a lot of difficulty in creating KPM test questions because of the lack of teacher references for creating test questions with KPM indicators.

b. Curriculum analysis
   The curriculum analysis resulted in learning objectives for the material on exponential functions and quadratic functions. The learning objectives produced are as follows: (1) interpreting the main characteristics of exponential functions; (2) modeling phenomena or data with exponential functions; (3) constructing exponential function graphs; (4) solving problems related to exponential functions; (5) interpreting the main characteristics of quadratic functions; (6) constructing quadratic function graphs; (7) solving problems related to quadratic functions.

c. Student analysis
   The student analysis resulted in students of class XI-6 of SMA Negeri 1 Pekanbaru who were the subjects in this study.

The design of the test questions produced at this stage was used as the initial product to move on to the next stage. The following is the design of the test questions produced which can be seen in Table 1.

Table 1. Example of Test Question Design that was developed

	KPM Indicator	Question Number
1.	Drawing conclusions in a general form (generalization)	1, 2
2.	Proving the validity of a statement (justification)	3, 4, 5
3.	Perform mathematical manipulation	6, 7, 8
4.	Drawing conclusions based on similarities (analogies)	9, 10, 11, 12
5.	Submitting a guess or predicting the answer (conjecture)	13, 14, 15

Self Evaluation Stage

The self-evaluation stage produced prototype I, namely 15 questions along with the grid, alternative solutions, and KPM test question assessment rubrics that were ready to be continued to the next stage.

Expert Review Stage

At this stage, prototype I was validated by 3 experts or validators, and produced a grid, 17 test questions, alternative solutions, and valid assessment rubrics. The validation score from the validator was analyzed and produced a score of 82.97% with the category of "very valid". In addition, the validator also provided suggestions and comments related to the test questions that had been developed to make them better. Examples of comments and suggestions from the validator and revision decisions on question number 9 can be seen in Table 2.

Table 2. Comments and Suggestions from the Validator Regarding Question Number 9

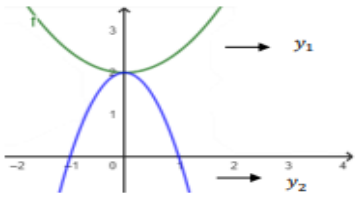
Validators	Comments	Revision decision
Validator-1	Add a picture to question number 9 so that students understand the question better.	Provide a clear picture for question number 9
Validator-2	-	
Validator-3	Provide a clear picture to question number 9	

From the validator's comments, improvements were then made to question number 9. Improvements to question number 9 can be seen in Figure 2. Before revision, and Figure 3. After revision.

Soal no 9

Andi menggambar dua grafik fungsi kuadrat yang terbuka keatas dan saling bersinggungan. Jika Andi menggambar grafik fungsi dengan fungsi berturut-turut$y_1 = \frac{1}{2}(x^2 + 4)$ dan $y_2 = 2(x^2 - \frac{k}{2} + \frac{k^2}{2})$. Maka tentukanlah nilai k yang memenuhi kedua fungsi tersebut!

Figure 2. Before Revision



Jika persamaan kedua grafik fungsi tersebut berturut-turut $y_1 = \frac{1}{2}(x^2 + 4)$ dan $y_2 = -2(x^2 - \frac{k}{2} - \frac{k^2}{2})$. Maka tentukanlah nilai k yang memenuhi kedua fungsi tersebut!

Figure 3. After Revision

One-to-one Stage

The one-to-one stage was carried out simultaneously with the expert review stage. At this stage, 3 non-test subject students with heterogeneous abilities worked on the KPM test questions on prototype I and unstructured interviews were conducted with the 3 students. From this stage, comments and input from students were generated regarding the readability of the KPM test questions. An example of input and comments from students on question number 4 can be seen in Table 3.

Table 3. Revision Suggestions and Decisions for question number 4

Learners	Comments	Revision decision
1 2 3	• It is better to explain what function is meant in question number 4 • Including difficult questions • Add the type of function referred to in question number 4	Adding an explanation regarding the type of function in question number 4

From the example of one of the suggestions and comments from students at the one-to-one stage in question number 4, improvements were then made which can be seen in Figure 4. Before revision and Figure 5. After revision.

Soal no. 4:
Jika $f(1) = 500,\ f(2) = 1000,\ f(3) = 4000,$
maka buktikan $f(n) = 2^{n-1}(500)$.

Figure 4. Before revision

Soal no. 4:
Jika diketahui nilai dari suatu fungsi eksponen
$f(1) = 500, f(2) = 1000, f(3) = 2000, f(4) = 4000.$
Maka buktikan $f(n) = 2^{n-1}(500)$.

Figure 5. After Revision

In Figure 3, it can be seen that the original question only stated the function value without telling what function was meant and this made students confused in working on the question. After improvements were made to Figure 4 by adding what type of function was meant by the question so that the question looked clearer and easier for students to understand. Based on the expert review and one-to-one stages, comments and input were obtained which were used as improvement materials for prototype I to produce Prototype II which will be continued at the small group stage.

Small Group Stage

At this stage, students were interviewed to see the readability of the questions, and the relationship between the questions presented with the material on exponential functions and quadratic functions. The interview results showed that the KPM test questions worked on at the small group stage had good comments. This shows

that the KPM test questions can be continued to the field test stage (large group). This stage produces prototype III.

Field Test Stage

The analysis produced at this stage consists of.

a. Internal validity analysis

Internal validity analysis is obtained based on students' answers when completing the KPM test questions. Assessment of students' answers is seen from the alternative solutions and assessment rubrics developed. An example of the assessment rubric developed can be seen in Figure 6.

Aspek yang Diukur	Kriteria Penilaian	Skor
Menarik kesimpulan berupa bentuk umum (generalisasi)	Tidak menjawab	0
	Melengkapi data dari beberapa data yang diberikan dengan tepat, tetapi tidak memberikan kesimpulan.	1
	Melengkapi data yang diberikan dengan tepat, serta mampu dalam menarik kesimpulan tetapi kesimpulan yang diberikan belum berupa bentuk umum	2
	Melengkapi data yang diberikan dengan tepat, memberikan kesimpulan berupa bentuk umum namun bentuk umum yang diberikan kurang tepat.	3
	Melengkapi data yang diberikan dengan lengkap dan benar, dan memberikan kesimpulan berupa bentuk umum dengan tepat.	4
Mengajukan dugaan atau memprediksi jawaban (konjektur)	Tidak menjawab	0
	Mengajukan dugaan tetapi tidak tepat	1
	Mengajukan berbagai dugaan tetapi sebagian dugaan dari jawaban ada yang belum tepat dan belum lengkap	2
	Mengajukan berbagai dugaan dengan benar tetapi jawaban masih memuat dugaan yang kurang lengkap	3
	Mengajukan berbagai dugaan dengan benar dan lengkap	4
Membuktikan keshahihan dari suatu pernyataan (justifikasi)	Tidak menjawab	0
	Memberikan bukti mengenai suatu pernyataan tetapi tidak benar	1
	Memberikan bukti mengenai suatu pernyataan namun terdapat beberapa kesalahan dan belum lengkap	2
	Memberikan bukti mengenai suatu pernyataan dengan benar tetapi belum lengkap	3
	Memberikan bukti dari suatu pernyataan dengan benar dan lengkap secara matematis	4
Melakukan manipulasi matematis	Tidak menjawab	0
	Melakukan manipulasi matematis namun tidak benar dan tidak lengkap	1
	Melakukan manipulasi matematis namun tidak lengkap serta masih terdapat beberapa kesalahan	2
	Melakukan manipulasi matematika dengan benar tetapi belum lengkap	3
	Melakukan manipulasi dengan lengkap dan benar.	4
Menarik kesimpulan berdasarkan keserupaan (analogi)	Tidak menjawab	0
	Menarik kesimpulan berdasarkan keserupaan suatu pernyataan namun tidak benar	1
	Menarik kesimpulan berdasarkan keserupaan pada suatu pernyataan namun terdapat beberapa kesalahan dan belum lengkap	2
	Menarik kesimpulan berdasarkan keserupaan pada suatu pernyataan dengan benar tetapi kurang lengkap	3
	Menarik kesimpulan berdasarkan keserupaan pada suatu pernyataan dengan benar dan lengkap	4

Figure 6. Example of the Assessment Rubric Developed

The student's answer scores obtained based on the assessment rubric were then analyzed for external validity and calculated using the t-test. In the t-test, there is a t_count value for each question item which is compared with t_table = t_α (dk = n-2) with a significance level of 95% and the t_table value obtained from 34 respondents is 2.03. Questions are said to be valid when $t_{count} > t_{table}$ and questions are said to be invalid when the t_count value $< t_{table}$.

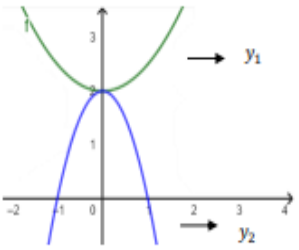
From the results of the external validity analysis, 15 valid KPM test questions were obtained. So that the 15 questions were reanalyzed to determine the reliability value, discriminatory power, and level of difficulty.

b. Reliability test

The reliability test was conducted by processing the students' scores related to 15 KPM test questions that had been declared externally valid. The results of the reliability test on the 15 valid KPM test questions had a value of 0.81 with a very high category. So that the 15 questions are very reliable in carrying out their measuring function.

c. Difficulty level test

The results obtained from the difficulty level test were that there were 3 KPM test questions that were categorized as difficult and 12 KPM test questions that were categorized as moderate. The 3 KPM test questions that were categorized as difficult were numbers 9, 13, and 14. Question number 9 contains the indicator "conducting mathematical manipulation" and numbers 13, 14 contain the indicator "drawing conclusions based on similarity (analogy)". This shows that students still have difficulty in conducting mathematical manipulation and are still unable to draw conclusions based on similarity (analogy). The questions that are categorized as difficult can be seen in Figure 7, Figure 8 and Figure 9.



Jika persamaan kedua grafik fungsi tersebut berturut-turut $y_1 = \frac{1}{2}(x^2 + 4)$ dan $y_2 = -2(x^2 - \frac{k}{2} - \frac{k^2}{2})$. Maka tentukanlah nilai k yang memenuhi kedua fungsi tersebut!

Figure 7. Question Number 9

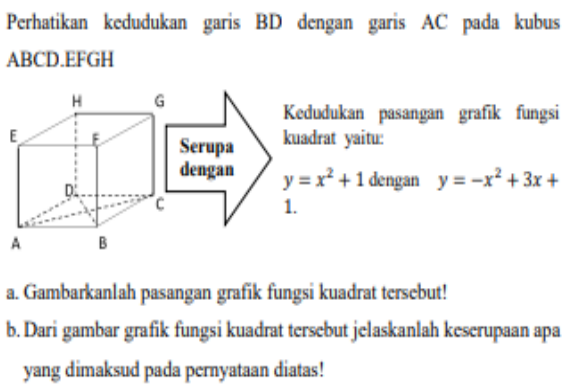


Figure 8. Question Number 13

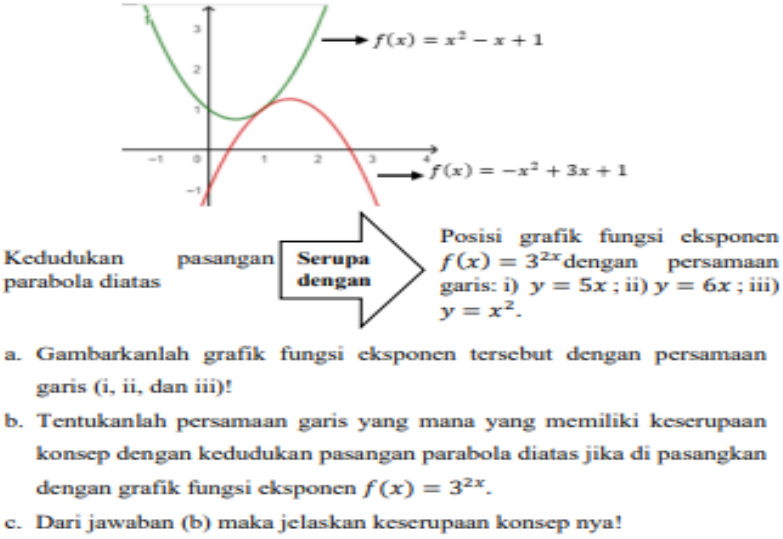


Figure 9. Question Number 14

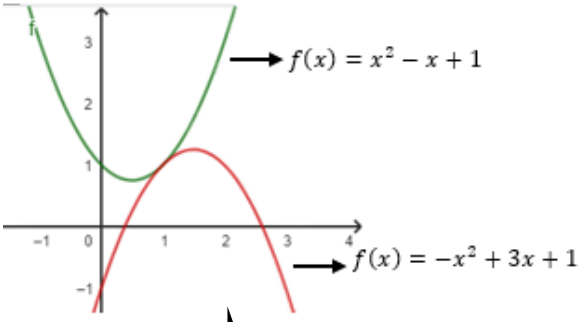
d. Distinguishing power test

The discriminating power analysis of the KPM test questions shows that out of 15 questions that have been considered valid, there are 10 questions with good discriminating power and 5 questions with sufficient discriminating power. The average discriminating power for the 15 questions is 0.44, so it is included in the good category. Therefore, from the perspective of discriminating power, the mathematical reasoning ability test questions that have been developed have good quality.

Based on the results of the analysis, 15 KPM test questions were obtained which were categorized as valid internally and externally, had good reliability values, difficulty levels, and discriminating power. The distribution of the 15 questions in the mathematical reasoning ability indicator is as follows: 2 questions meet the indicator of drawing conclusions in the form of general forms (generalization), 1 question meets the indicator of proving the validity of a statement (justification), 3 questions meet the indicator of mathematical manipulation, 2 questions meet the indicator of drawing conclusions based on

similarity (analogy), 3 questions for the indicator of submitting conjectures or predicting answers (conjecture). Then there are 4 questions that meet two KPM indicators consisting of 2 questions that meet the generalization and justification indicators, and 2 questions that meet the generalization and analogy indicators. Examples of 5 questions that were developed and in accordance with the KPM indicators can be seen in Table 4.

Table 4. Question items developed in accordance with the KPM Indicators

KPM Indicator	Question
Drawing conclusions in a general form (generalization)	Pada hari minggu Ani, Ati, dan Febi pergi bersepeda di Car Free Day (CFD). Namun, saat bersepeda Ani terjatuh akibat tersenggol pesepeda lainnya sehingga menyebabkan luka yang cukup parah di lututnya. Ati dan Febi kemudian membawa Ani ke klinik terdekat. Sampai di klinik Ani langsung ditangani oleh dokter, dokter kemudian menyuntikkan Ani obat pereda rasa nyeri. Dosis obat yang disuntikkan dokter tersebut adalah 60 mikrogram. Setelah 30 menit penyuntikkan, $\frac{1}{2}$ dosis tersebut akan luruh dan dikeluarkan dari dalam tubuh Ani. Proses tersebut terus berulang selama 30 menit. Dengan menggunakan fungsi eksponen, tentukanlah berapa kadar obat pereda nyeri yang tersisa di dalam tubuh Ani setelah 2 jam, dan 3 jam paska penyuntikkan dan buatlah bentuk umum untuk menghitung sisa kadar obat tersebut pada (x) waktu dalam 30 menit berikutnya!
Proving the validity of a statement (justification)	Dimas melambungkan sebuah bola dengan melewati tiang sehingga membentuk suatu parabola. Jika diketahui titik puncak pada bola tersebut adalah $(3,8)$, dan titik potong bola tersebut terhadap tiang adalah $(0,6)$ maka tunjukkanlah bahwa fungsi kuadrat tersebut adalah $f(x) = -\frac{2}{9}x^2 + \frac{4}{3}x - 6$.
Perform mathematical manipulations	Jika suatu grafik fungsi kuadrat dengan fungsi $f(x) = x^2 + dx + 9$ menyinggung garis $y = 2x + 9$, maka tentukan nilai d yang memenuhi dan nilai titik puncak grafik fungsi tersebut!
Drawing conclusions based on similarities (analogies)	Perhatikan kedudukan pasangan parabola berikut ini.  Kedudukan pasangan parabola diatas **Serupa dengan** Posisi grafik fungsi eksponen $f(x) = 3^{2x}$ dengan persamaan garis: i) $y = 5x$; ii) $y = 6x$; iii) $y = x^2$. a. Gambarkanlah grafik fungsi eksponen tersebut dengan persamaan garis (i, ii, dan iii)! b. Tentukanlah persamaan garis yang mana yang memiliki keserupaan konsep dengan kedudukan pasangan parabola diatas jika di pasangkan dengan grafik fungsi eksponen $f(x) = 3^{2x}$. c. Dari jawaban (b) maka jelaskan keserupaan konsep nya!
Making a guess, or predicting the answer	Seorang arsitek merancang suatu lintasan permainan *skate board* yang berbentuk parabola dengan fungsi kuadrat $f(x) = ax^2 + bx + c$. Arsitek tersebut bermaksud untuk menentukan titik terendah dari lintasan *skate*

(conjecture)	*board* tersebut, dengan $(a > 0)$. Jika arsitek mengubah kemiringan lintasan *skate board* tersebut dengan mengubah nilai a, maka perkirakanlah: a. Bagaimana pengaruhnya terhadap titik terendah lintasan *skate board*? b. Bagaimana pengaruhnya terhadap kedalaman titik terendah lintasan *skate board*? c. Bagaimana kestabilan lintasan *skate board* tersebut? d. Dari ketiga jawaban (a, b, c) berikanlah kesimpulan terhadap pengaruh perubahan nilai a pada lintasan *skate board*!

4. Conclusion

Based on the results of the research and discussion, it is concluded that this study produced 15 KPM test questions on the material of exponential functions and quadratic functions that are internally valid, externally valid, have good reliability values, difficulty levels, and differentiating power. The test questions that were compiled were able to train students' mathematical reasoning skills. This is evidenced by the results of interviews conducted with students after working on the KPM test questions.

As a suggestion, that research on the development of KPM questions needs to be developed again with different mathematical materials and using KPM indicators that have not been used. In addition, this test instrument can be used as a reference for teachers to train students' mathematical reasoning skills.

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