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Development of Higher-Order Thinking Skills test instrument on Quadratic Equations (HOTS-QE) for Secondary School Students

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Abstract

The Higher-Order Thinking Skill Test Instrument on Quadratic Equations (HOTS-QE) was developed to measure the level of HOTS on the topic of quadratic equations among secondary school students. The HOTS-QE instrument consists of 17 structured subjective items divided into two smaller questions according to the three levels of HOTS, namely applying, analysing, and evaluating. This study proposes a design and development research (DDR) approach via a development research that was done through an organised and systematic process. The DDR-oriented development process comprised seven stages namely source analysis, theory, development, content validity, validation of the HOTS domain accuracy, language validity, and pilot study. The development of the HOTS-QE instrument comprised seven stages, namely source analysis, theory, development, content validity, validation of the HOTS domain accuracy, language validity, and pilot study. The content validity of the instrument was evaluated by five mathematics education experts. The results showed that the item content validity index (I-CVI) value of each item was above 0.70 while the content validation per scale (S-CVI) value was 0.98. Results from the interrater evaluation also showed that the HOTS level accuracy of the instrument items had achieved the Cohen's Kappa coefficient value of 0.63. In addition, findings from the pilot study also showed that the Cronbach's alpha coefficient value was 0.79, the discrimination index value of each item was between 31.11% to 66.67%, and the difficulty index values were between 40.74% to 70.00%. These results suggest that the HOTS-QE instrument has an acceptable level of validity. The development of this instrument provides a more varied learning assessment that can foster students' interests in learning, help them to improve HOTS, and provide opportunities for students to directly apply the knowledge of quadratic equations learned at school in their daily life.

Keywords: Test instrument, Higher-Order Thinking Skills (HOTS), quadratic equations.

Introduction

High-Order Thinking Skills (HOTS) is nothing new, however, previous studies have offered different definitions about the concept. Some definitions include flexible transferring and reasoning in fact-memorization skills (Richland & Simms, 2015), skills that exceed the level of remembering facts (Thomas & Thorne, 2010), as well as in-depth creative and critical thinking processes that enable one to solve complex problems (Brookhart, 2010), ability to apply new knowledge in new situations with the potential to produce a variety of answers (Singh & Marappan, 2020), integrated application of students' knowledge, skills, and values across fields (Abdullah et al., 2020), widespread use of the mind to construct or find something unique (Sulaiman et al., 2017), non-routine problems that require mental processes and exhibit solutions from various perspectives (Tan & Halili, 2015), disuse of algorithms and possibility of various solutions (Low & Teh, 2016), and ability to parse, translate, create, reflect, and relate something to the current situation (Othman & Kassim, 2018). All these definitions seem to suggest that HOTS refers to the highest level in the hierarchy of cognitive processes that involves a person acquiring new information, associating such information with existing knowledge, and extending it to solve a complex problem or achieve a goal.

From the coof the mathematics curriculum, HOTS not only refers to students' ability to apply knowledge, skills, and values in reasoning and reflection but also the ability to solve problems, make decisions, innovate, and be able to create something. The interpretation of HOTS in the field of education can be further detailed as teaching and learning in the form of inquiry, problem-solving, research and project-based activities, various in-class approaches and activities, discussion, metacognition, and graphic management through

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the use of thinking tools such as mind maps and high-level questioning that facilitate teaching and learning. HOTS is regarded as the use of creative thinking to face new challenges. Individuals faced with a problem should be able to deepen, translate, analyse, and interpret any obtained information. This is because HOTS helps students to critically evaluate the information before drawing initial conclusions and generalisations from the information. Therefore, it can be concluded that such thinking skills should be embedded in the learning process to encourage critical and creative thinking as well as helping students to provide justification when solving complex mathematical problems, especially those related to the topic of quadratic equations.

Quadratic euquations is considered as a prominent topic in the school curriculum because it helps to create a network of knowledge between topics in mathematics such as linear equations, functions, and polynomial derivatives (Sağlam & Alacacı, 2012). It also serves as an important component for making strong representations in problem solving within a variety of disciplines such as physics, engineering, and structural design. This is mainly due to its suitability in describing the idea in the form of a realistic model or similar to real everyday life situations. Nevertheless, findings by Kim How et al. (2022) showed that many students in Malaysia only possess mastery in basic quadratic equations concepts without having the ability to apply the knowledge while experiencing significant problems and difficulty to solve non-routine questions. Such issue thus justifies the need for further research on the relationship between HOTS and quadratic qquations as the integration of HOTS into the concept of quadratic equations can help teachers to assess students' level of HOTS mastery when the quadratic equations concept is translated into new contexts, real daily life situations, as well as various questions and stimulus.

Although the topic of quadratic equations is considered simple and involves only basic skills, human daily lives commonly revolve around adapting the concept of quadratic equations such as in the field of sports and architecture. In sports, quadratic equations are used in sporting events that feature projectiles such as shot put, discus throw, and javelin. On the other hand, we often see parabolic curved constructions in architecture that are closely related to the concept of quadratic equations (Yeow et al., 2019). Therefore, students who fail to understand such basic concept at an early stage are likely to fossilise the wrong concept for further learning. This is in line with Watt (2005) who stated that students' difficulty in pursuing science courses at the university level is closely related to their failure in mastering the basic knowledge of quadratic equations, which is a key prerequisite for accessing higher mathematical knowledge. In line with this, Hendel (2018) has outlined seven main classes of verbal problems in the form of real situations that can be modelled and solved using quadratic equations. The examples of situations for each class of verbal problems are shown in Table 1.

Despite its importance, solving quadratic equations remains as the most challenging algebraic topics to be mastered as compared to other contents in the mathematic syllabus (Hu et al, 2021). Many students are still struggling

Table 1: Seven main classes of verbal problems in the form of real situations that can be modelled and solved using the concept of quadratic equations

Types of Problem	*Common verbal problems (Example)*
Projectile/Gravity	A water rocket is launched from a rig. At time t seconds after launch, the height of the water rocket from the ground surface is h m with the condition $h = -2t^2 + 7t = 15$. When will the water rocket arrive at the ground level?
Suspension bridge	A suspension bridge consists of two towers tied together. The bridge has a height of 100 metres from the road surface and a distance of 400 metres between the two towers. The cable that hangs the bridge touches the centre surface of the bridge. Find the height of the cable at a distance of 100 metres from the centre of the bridge.
Profit	During the Entrepreneurship Day at Anderson Secondary School, the chairman of the Science Association planned to sell cheesecake. Initially, they want to sell 56 pieces of cheesecake for 2 dollars a piece. If they increase the price by 25 cents per piece, the total number of cheesecakes sold will be reduced by 2 pieces for each time the price increases. How many pieces of cheesecake and the price for a piece of cheesecake that needs to be sold by the association to make a profit of 160 dollars?
Geometry	A cuboid-shaped water tank has a length of $3x$ m and width $(x + 2)$ m. When the tank is filled with 252 m^3 of water, the height of the water level in the tank is 3.5 m. Find the value of x.
Rate of change of time/ Work/Distance	Two buses, A and B, started moving from the same bus station. Bus A moves north while Bus B moves west. After 2 hours, the distance between Bus A and Bus B is 150 km. If the average speed of Bus B exceeds Bus A by 15 km h^{-1}, find the distance of Bus A and Bus B from the bus station.
Number Theory	Given that the sum of two numbers is 5, while the product of the numbers is 6. What are the numbers?
Parabolic reflection antenna	If a parabolic reflection antenna has a diameter of 20 cm and a depth of 5 cm, find the focus of the antenna which is where the centre of the wave is emitted.

to find the right solutions (Utami & Jupri, 2021). Numerous past studies reported that students often make quadratic equation mistakes and these errors also occur at all levels. Among the contributing factor to such weakness is that students find it difficult to give meaning or understand the terms used to represent the roots of the quadratic equations (Thomas & Mahmud, 2021). They also often make mistakes when solving quadratic equations, especially in the process of conducting operations to reach the solutions and finding the possible values for substitute variables along with the lack of understanding about fractions, integers, linear equations, negative numbers, and basic mathematical properties such as algebraic expansion (Herawaty et al., 2021). The study by Vaiyavutjamai et al. (2005) also reported that many students do not know that quadratic equations have more than one root. For example, when performing the x elimination operation for the equation $2x^2 = 3x$, students are unaware that one of the root values for the equation is 0. This indicates their weakness in mastering the zero multiplication theorem (López et al., 2016). Moreover, students also do not understand the concept of root which refers to different entities representing the value of the variable x to satisfy the quadratic equation. For example, in solving the equation of $(x-3)(x-5)=0$, even if students are able to determine the root value of the quadratic equation is $x=3$ or $x=5$, yet they do not assume that the two values of x represent different variable values. When reviewing the solution steps, students will simultaneously substitute both values of the variable x obtained in the equation, namely $x=3$ in $(x-3)$ and $x=5$ in $(x-5)$. Since the multiplication substitution product of the x value at $(0)\times(0)$ will be equal to the value of '0', students will conclude that each step in the solution procedure is correct and accepted (Didis & Erbas, 2015).

Therefore, the development of the Higher-Order Thinking Skill Test Instrument on Quadratic Equations, or HOTS-QE, for secondary school students is deemed necessary. Starting with only 20% of questions in 2014, the percentage of HOTS questions in public examination will continue to increase up to 50% in 2021 (Ministry of Education Malaysia, 2018). Furthermore, quadratic equations is indeed a difficult topic (Güner, 2017). In fact, studies related to the teaching and learning of quadratic equations are also poorly conducted (Didis & Erbas, 2015; Teh, 2015). This further justifies the urgent necessity to develop the HOTS-QE test instrument that will provide a more varied learning assessment that can foster students' interests in learning, help them to improve HOTS, and provide valuable opportunities for them to directly apply the quadratic equation knowledge learned at school in their daily life.

In conclusion, it is important to use a valid and highly reliable test to identify students' level of HOTS and weaknesses on the topic of quadratic equations. This statement is supported by the findings of Thomas and Mahmud (2021) which suggest that overcoming weaknesses such as errors in quadratic equations at an early stage will have a major impact on complex mathematics learning in the future. Although HOTS-based learning approaches are often used in mathematics classes, no specific tests aimed at identifying the level of HOTS in quadratic equations have been developed. Therefore, the present study was conducted based on the following objectives:

1. To develop a Higher-Order Thinking Skills test instrument on Quadratic Equations (HOTS-QE) for secondary school students.
2. To validate the Higher-Order Thinking Skills test instrument on Quadratic Equations (HOTS-QE) for secondary school students
3. To determine the reliability of the Higher-Order Thinking Skills test instrument on Quadratic Equations (HOTS-QE) for secondary school students.

Research Methodology

This study employed the Design and Development Research (DDR) approach to identify whether the teaching materials developed can affect the three levels of HOTS, namely applying, analysing, and evaluating the topic of quadratic equations. To measure the effectiveness of the intervention, respondents had to complete the HOTS-QE instrument in the form of structured problem solving before and after the intervention was conducted. The instrument also assessed students' existing knowledge about the topic of quadratic equations. The focus of this study is the development of HOTS-QE which was used to evaluate effectiveness covering several levels, ranging from source analysis to the validation of a valid test instrument used to identify HOTS for the topic of quadratic equations. The methodological framework for the development of the Higher-Order Thinking Skill Test Instrument on Quadratic Equations (HOTS-QE) is shown in Figure 1.

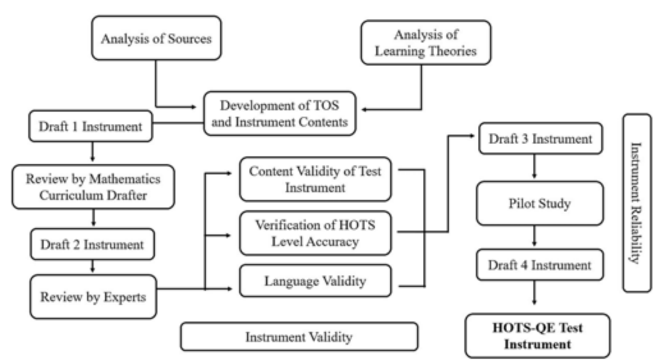


Fig. 1: Methodological framework for the development of the Higher-Order Thinking Skill Test Instrument on Quadratic Equations (HOTS-QE)

Findings

Stage 1: Source Analysis

The purpose of source analysis was to identify the basis, guideline, and benchmark of HOTS instrument development prior to the actual process. All information gathered were summarised using the Checklist Rubric of HOTS-QE Items as shown in Figure 2. All items in the test instrument were constructed based on the Standard Document for the Curriculum and Assessment of Form 4 and 5 Mathematics (Curriculum Development Division, 2018), Malaysian Mathematics Textbook (Yeow et al., 2019), Mathematics Questions Analysis Book (Razali et al., 2019), and HOTS application handbook (Curriculum Development Division, 2014). In addition to using the existing local references, the test items were also constructed based on international assessment items including the GCSE 9-1 Exam Question (TES, 2018), Australian Mathematical Science Institute (2011), and the Cambridge Queensland Mathematics B Year 11 textbook (Ousby et al., 2008). Students' achievement in this test was also aligned with international assessments and standards.

While formulating the items in this instrument, the researcher had also taken into account that each item must meet all or almost all of the HOTS characteristics recommended by the Curriculum Development Division, Ministry of Education Malaysia as shown in Table 2:The HOTS items constructed in this test also adhered to the conformity across three aspects, namely Curriculum Conformity, Opportunity Conformity, and Specification Conformity (Malaysian Examination Board, 2013). Curriculum conformity is an important aspect because having HOTS items that are outside the curriculum track can dispute the curriculum validity of the items (Madaus, 2013). In addition, these items must also comply with the coincidence of opportunity, in which the situations contained in the questions are part of the experience that the students have gone through or there are external exposures such as sharing by teachers or mass media. Finally, these test items must also comply with the specification in which the items' constructs are geared towards the specification rubric set in the Table of Specification (TOS).

Subsequently, the construction of these items should be done by considering all components in the PISA Mathematical Literacy Framework (Thomson et al., 2013; Shiel et al., 2007) in order to meet the international testing standards. The components are (i) situation and context where the problem is appropriate to the situation for it to be a stimulus, (ii) mathematical contents which include four comprehensive areas of Mathematics namely quantity, space and form, change and relationship, and uncertainty, and (iii) competency and process where the questions can prompt students to use cognitive poses that consist of three clusters of competency (connect, reproduce, and reflect) in attempting to solve the problems. The key features of each component in the PISA Mathematical Literacy Framework are shown in Figure 2.

Table 2: Characteristics of Higher-Order Thinking Skills items

Characteristic	*Description of Higher-Order Thinking Skills items characteristic.*
Stimulus	The items provide sufficient information for students to plan and generate ideas.
Various cognitive levels	Prompt various forms of students' responses and answers by varying task words to assess different levels of thinking.
Unusual context	Using new situations outside the classroom by encouraging students to think more deeply.
Real-life situations	Encourage students to solve real-life problems using learning from various disciplines.
Non-recurring items	The use materials beyond textbook materials, workbooks, exercise books, and a variety of educational resources.

(Curriculum Development Division, 2014).

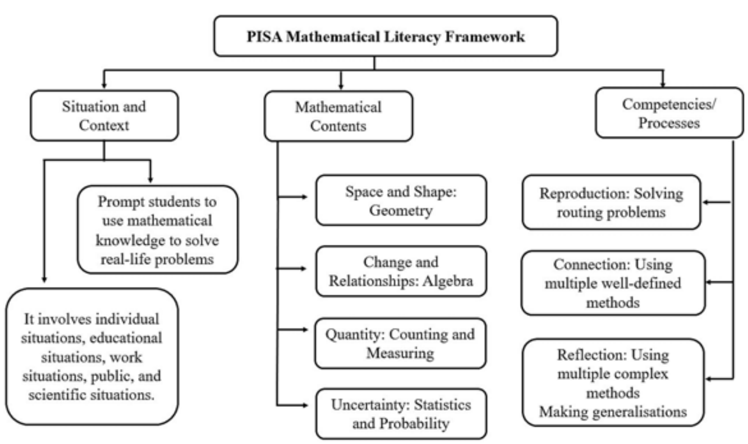


Fig. 2: PISA Mathematical Literacy Framework (Thomson et al., 2013)

Stage 2: Analysis of Learning Theories

Content validity is based on the perception and theoretical constructs that are intended to be assessed (Newman & Pineda, 2013). Thus, in this study, the APOS Theory (Action, Process, Object, Schema) was employed as the theoretical framework to determine the students' level of cognitive development in understanding the topic of quadratic equations. The APOS theory is a theoretical framework that was introduced by Dubinsky et al. (1991) along with several other studies. In line with the researcher's goal of focusing on HOTS, the APOS was deemed appropriate to assist in the systematic formulation of HOTS learning criteria in line with the students' cognitive development. Otherwise, the contents of the test instrument will be boring or too difficult for them. The APOS theory begins with actions resulting from external stimulus and subsequently moves in response to processes and objects (Listiawati & Juniati, 2021).

Effective learning process often occurs through actions between students and the contents of the lesson. The core idea of this theory is that students act by receiving knowledge input, process by choosing what is learned, and impose meaning to something learned in the form of objects. The schema (cognitive structure or mental model) formed will contribute meaning and organise each knowledge construct in enabling students to think further and broadly from the obtained information. The formation of the quadratic equations concept within the students' mental model is in accordance with each sequence of constructs in the APOS Theory as shown in Table 3.

Stage 3: Development of the Table of Specification (TOS) and Instrument Contents

A Table of Specification (TOS) was constructed as a guideline to construct the test items based on the hierarchical difficulty level of Anderson and Krathwohl's (2001) Taxonomy Model. The TOS comprised a matrix representing the number of questions tested in the instrument according to the topic and the three levels of HOTS, namely applying, analysing, and evaluating. Using the TOS as a guide is believed to contribute towards improving the content validity of the test (Fives & DiDonato-Barnes, 2013). It also prevents the question drafters from being careless in constructing the questions without planning, which can limit the number of dimensions being measured.

The method of presenting these subjective and structured test questions is in accordance with the Malaysian Examination Board. The researcher opted for subjective questions over objective questions because the latter is more suitable to assess students' lower-order thinking skills (Momsen et al., 2010), particularly from the aspect of recalling learning facts (Bakar, 2014). On the other hand, subjective questions are more consistent and aligned with the research objectives where they can be used to assess students' learning skills at a high level such as synthesising, analysing, and evaluating (Shaban, 2014). Subjective questions also offer more reliable results at low cost (Sahin, 2017) and provide opportunities for students to demonstrate skills, express ideas, and organise ideas based on logic.

All items in the test were numbered from 1 to 17. The test time allotted was two hours by taking into account the difficulty levels of these items. Each structured subjective question was broken down into two or three small correlated questions in stages. In terms of the weightage of marks, the percentage of marks offered was based on the Malaysian Examination Board standards where each question must be between four to seven marks. The appropriateness of the weightage of marks was based on the difficulty level of the test items being assessed. For example, more weightage of marks was given for items with higher level of difficulty. This is because in deciding on the weightage of marks, the researcher had taken into account the aspect of cognitive level and the

Table 3: Example of the APOS Theory Construct Sequence in the stud*y*

Topic	*APOS Theoretical Framework*	*Example of Reflective Abstraction (Cahyani & Rahaju, 2019)*
Quadratic Equations	Action	• Students can write a general form of a quadratic equation with the conditions that *a*, *b*, and *c* are constants, $a \neq 0$, and *x* is a variable. • Students can identify two main features of a quadratic expression in one variable: • has only one variable.the highest power of the variable is 2.
	Process	• Students are able to form quadratic functions and relate them to quadratic equations. • Students can determine the root of a quadratic equation with 3 methods of factorization, namely: a. Cross method b. Using *a* and *c* c. Using formulas
	Object	• Students can explain the meaning of quadratic equation $ax^2 + bx + c$ where the value of *x* satisfies the equation. $= C$ • Students can make generalisations about the effects of changes in *a*, *b*, and *c* on the root values of quadratic equations.
	Schema	• Solving mathematical problems in the form of HOTS involves the concept of quadratic equations.

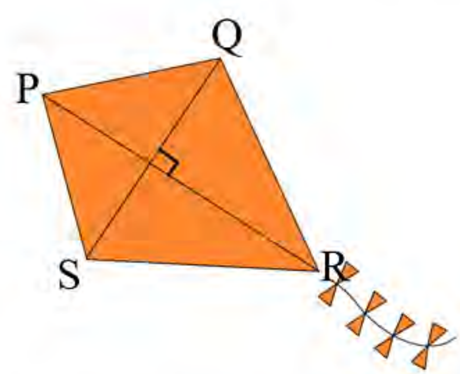
time required to complete the questions. Such scoring method involving the weightage of marks based on the difficulty level of the questions helped to better distinguish excellent students among the good.

After considering the HOTS items construction guidelines, the researcher proceeded to formulate the specifications and construct a HOTS Items Checklist Rubric to ensure that each item built in the test was in accordance with its recommended specifications. The rubric provided specific criteria to be used as a guideline for the researcher to evaluate every excellent HOTS item in the test instrument. This process also enabled the researcher to produce a better plan in the construction of HOTS items to meet the research objectives. Suggestions and examples of HOTS items in the testing and evaluation of the items using the HOTS Items Checklist Rubric are shown in Figure 3.

Once all HOTS items were formulated and met the rubric's criteria, they were then adjusted based on the Table of Specification (TOS).

Table 4 shows 17 structured subjective questions divided into two sub-questions according to the Bloom's Taxonomy domain. In developing the assessment format, particular

The figure below shows a kite PQRS. The diagonal lengths of PR and QS are $(3x+5)$ cm and $(2x-8)$ cm respectively.



(i) Given that the area of the kite PQRS is 550 cm^2, form a quadratic equation for the area of the kite PQRS in x.
(ii) Next, calculate the length of the diagonal PR.

Higher-Order Thinking Skills Items Checklist Rubric								
Bloom's Taxonomy Cognitive Domain			*Agreement*			*PISA Mathematical Literacy Component*		
Applying	Analysing	Evaluating	Curriculum	Opportunity	Specification	Situation & Context	Mathematics Contents	Competency and Process
(ii)	(i)		✓	✓	✓	✓	✓	✓

HOTS Item Characteristics				
Stimulus	*Various Levels of Skills*	*Unusual Content*	*Real-Life Situation*	*Non-Recurring Item*
✓	✓	✓	✓	✓

Fig. 3: Example of HOTS item in the HOTS-QE instrument and HOTS Items Checklist Rubric.

Table 4: Table of Specification (TOS) Test Instrument

Cognitive Domain		*Low*		*Medium*		*High*		
Topics	*ITEM/ DIFFICULTY LEVEL*	*REMEMBERING*	*UNDERSTANDING*	*APPLYING*	*ANALYSING*	*EVALUATING*	*CREATING*	*TOTAL*
	1			(i)		(ii)		
	2			(i)				
	3			(i)	(ii)			
	4			(i)		(ii)		
	5			(i)		(ii)		
	6				(i)			
	7			(i)		(ii)		
	8				(i)			
QUADRATIC EQUATIONS	9			(i)		(ii)		
	10					(i)		
	11			(i)	(ii)			
	12			(i)	(ii)			
	13			(i)	(ii)			
	14			(i)	(ii)			
	15			(i)	(ii)			
	16			(i)	(ii)			
	17					(i)		
TOTAL NUMBER OF QUESTIONS				13	9	7		29
PERCENTAGE (%)				45%	31%	24%		

priority was given on aligning it with the national curriculum. Therefore, the assessment format was designed based on the Curriculum Development Division (2018) where the context of HOTS application in the national school system defines HOTS as thinking up to the top four levels of the taxonomy namely applying, analysing, evaluating, and creating. Thus, three levels of the HOTS cognitive domain were tested in the developed instrument namely applying, analysing, and evaluating. Overall, these subjective questions comprised a combination of 13 applying-level, 9 analysing-level, and 7 assessing-level questions.

Stage 4: Verification of Test Instrument Contents

All items in a test will be considered to have high content validity if all domains or constructs reviewed are good and accurate (Creswell, 2012) and appropriate to the scope and objectives of the respective field of study (Md Zahir et al., 2019). Creswell (2007) suggests that determining the content validity of a test can be done by obtaining the evaluation, feedback, and opinion from field experts.

For the purpose of improving the content validity of the test instrument, the TOS and preliminary draft of the test instrument were evaluated by a national mathematics curriculum drafter who was a senior lecturer of mathematics education at a public university. All feedback and recommendations received were taken into consideration in making improvements to the instrument. Content validity assessment from the aspect of test items' suitability with the field of study was determined by referring to five experts in mathematics education and pure mathematics. This is in line with Shrotryia and Dhanda (2019) who recommend a minimum of three field experts to determine the content validity of an item with no maximum number of experts. Furthermore, the selection of field experts in this study was based on the criteria recommended by Yazdanmehr and Akbari (2015) in which the experts must have a minimum of five years of work experience, possess specific experience such as senior lecturers of mathematics education, and directly involved in related study such as Mathematics learning management. Table 5 shows the panel of experts involved in contributing to the assessment.

Table 5: Summary of content validity experts' background

Expert	*Position*	*Field of Expertise*	*Institution*	*Working Experience*	*Highest Education Level*
P1	Associate Professor	Mathematics Education	Universiti Kebangsan Malaysia	24 Years	Ph.D
P2	Senior Lecturer	Mathematics Education	Universiti Teknologi Malaysia	7 Years	Ph.D
P3	Senior Lecturer	Mathematics Education	Teachers Institute of Malaysia	24 Years	Ph.D
P4	Senior Lecturer	Pure Mathematics and Statistics	Universiti Malaysia Sabah	12 Years	Ph.D
P5	Subject Matter Expert Teacher	Mathematics Curriculum	Ministry of Education Malaysia	12 Years	M.Ed

Following their agreement to contribute to the study, the panel of experts were supplied with the Content Validity Rubric for them to examine the content validity of every item in the test. This included aspects such as the alignment of quadratic equations contents with students' cognitive level, the difficulty level of the questions based on the three levels of HOTS, the questions' standard according to the Malaysian Examination Board and PISA Mathematical Literacy Framework, and test consistency. The Content Validity Rubric required the experts to indicate the content validity index for each item (I-CVI) using four ordinal scales. They could also provide suggestions for improvement or highlight any deficiencies identified in each item by filling in the "Expert Review" column.

The I-CVI was determined by considering the average level of suitability given by the experts. According to Tilden, Nelson & May (1990), the acceptable I-CVI value is ≥ 0.70 with higher values indicating a more appropriate content validity. In this study, I-CVI and S-CVI was calculated using the following formula (Polit & Beck, 2006):

$$\text{CVI for Item (I-CVI)} = \frac{\text{Agreed item}}{\text{Number of expert}}$$

$$\text{CVI for Scale (S-CVI)} = \frac{\text{Sum of I-CVI scores}}{\text{Number of item}}$$

Besides determining the I-CVI index, all comments given by the experts were used to further improve the test items. This greatly assisted to improve the content of the test instrument. Table 6 shows the I-CVI score for each test item as evaluated by the experts.

After determining the content validation index for each item, the next process was to calculate the content validation per scale (S-CVI). The S-CVI calculation was conducted by finding the ratio of the I-CVI additive yield for each item received versus the total instrument items, where S-CVI is the average item content validity score for the instrument (Polit & Beck, 2006). It was found that the S-CVI value for the HOTS test instrument was 0.98 and all items were deemed appropriate and acceptable because the I-CVI value of each item was above 0.70. The S-CVI also showed that the content

Table 6: Content validity scores for the instrument items

HOTS Item	*Question*		*Number of Experts*	*Number of Agreement*	*I-CVI*
1	1	(i)	5	5	1.00
2	1	(ii)	5	5	1.00
3	2		5	4	0.80
4	3	(i)	5	5	1.00
5	3	(ii)	5	5	1.00
6	4	(i)	5	5	1.00
7	4	(ii)	5	5	1.00
8	5	(i)	5	5	1.00
9	5	(ii)	5	5	1.00
10	6		5	4	0.80
11	7	(i)	5	5	1.00
12	7	(ii)	5	5	1.00
13	8		5	5	1.00
14	9	(i)	5	5	1.00
15	9	(ii)	5	5	1.00
16	10		5	4	0.80
17	11	(i)	5	5	1.00
18	11	(ii)	5	5	1.00
19	12	(i)	5	5	1.00
20	12	(ii)	5	5	1.00
21	13	(i)	5	5	1.00
22	13	(ii)	5	5	1.00
23	14	(i)	5	5	1.00
24	14	(ii)	5	5	1.00
25	15	(i)	5	5	1.00
26	15	(ii)	5	5	1.00
27	16	(i)	5	5	1.00
28	16	(ii)	5	5	1.00
29	17		5	5	1.00

validity assessment for the test was good and excellent, with the minimum S-CVI value accepted was 0.80 to reflect high content validity (Shrotryia & Dhanda, 2019). The researcher also considered all written comments from the panel of experts to improve the meaning, use of mathematical terms, and structure of the items arrangement. Among the comments for improvement include the need to have more specific problems so that students are able to formulate the situation into mathematical form. For example, the question "… where x is the distance, in m" was changed for it to have a clearer sentence "… where x is the throwing distance, in m". In addition, the experts also suggested that the scoring scheme should be adjusted with each solution step.

Stage 5: Verification of HOTS Level Accuracy in the Test Instrument

Three cognitive levels in the HOTS domain (i.e., applying, analysing, and evaluating) were used in this study to develop the instrument items. For the purpose of verifying the level of accuracy, all test items were reviewed and evaluated by a panel of experts comprising a lecturer in mathematics education who holds the position of an Associate Professor and a doctorate degree in Mathematics Education and an Subject Matter Expert Teacher with more than 10 years of experience in teaching Mathematics at national secondary school as well as being a national public examination examiner. The appointed experts served as interraters (experts' agreement with the researcher) to confirm the HOTS domains level as set by the researcher.

The validity assessment was conducted using the Cohen's Kappa coefficient measurement to determine the experts' level of agreement on the HOTS level of every item in the test. This is in line with Wahid (2019) who advocate on the use of Cohen's Kappa coefficient to validate the accuracy level of thinking in the evaluation sheet as it involves two levels of agreement scale and ensures consistency between the two interrater evaluators on the items. A Cohen's Kappa coefficient value between 0.6 to 0.8 is considered adequate with higher values indicating higher reliability (Landis & Koch, 1977).

The experts evaluation results showed that the HOTS level accuracy of the test items had met the Cohen's Kappa measurement level of 0.63. This indicates that the fixation performed by the researcher had obtained the Cohen's Kappa measurement level between 0.61 to 0.80, thus suggesting indicates a good agreement value (Foody, 2020). Following the experts' recommendation, several modifications and improvements were done on problems 11(ii) and 24(ii) to better suit the intended HOTS level. The experts recommended that the cognitive domain for both questions should be based on the evaluating construct rather than analysing. Therefore, the HOTS level for these questions were altered to suit the suggested cognitive domain.

Stage 6: Language Validity

Prior to the pilot study, a language validation process was done on the HOTS-QE instrument by a language expert who was a senior lecturer from the Department of Languages, Teachers Training Institute and holds a doctorate degree in language. The language validity process is important to revise, correct, and improve the use of language in the HOTS-QE instrument for it to be more accurate and appropriate to the targeted participants. Among the comments received from the language expert were spelling corrections as well as the use of capital letters, discourse markers, and exclamation marks. Based on these comments, several questions were modified and improved to ensure that the items were more specific and assist the participants' understanding on its intended meanings.

Stage 7: Pilot Study

Following the validity assessment of the test instrument, the next process was to conduct a pilot study for the purpose of reliability assessment. This was done through the discrimination index, difficulty index, and Cronbach's alpha coefficient measurement.

The original draft of the test instrument consisted of 17 subjective questions in the form of structured problem-solving. The pilot study was done in December 2021 involving 33 Form Four students who were recruited with the permission of a national secondary school in Tawau. Form Four, in the context of this study, refers to secondary school students who are 16 years old or in Grade 10. They were allocated with a time period of two hours to answer the questions in the HOTS-QE instrument.

Validity and Reliability Results

The discrimination index, difficulty index, and Cronbach's alpha coefficient were determined using the ANATES V4 software (Zulnaidi et al., 2020). Results for the pilot study are shown in Table 7.The results revealed that 14 questions in the HOTS-QE instrument were categorised as having good discrimination index between 31.11% to 66.67%, subsequently suggesting on its appropriacy to be used in a real learning context. Meanwhile, Questions 12 and 13 recorded a moderate discrimination index (29%) and can be further improved. Also, Question 11 obtained a discrimination index of less than 19%, hence suggesting that it is inappropriate and should be modified as it cannot distinguish between high-achieving and low-achieving students (Ebel & Frisbie, 1986). Therefore, Question 11 was deleted from the HOTS-QE instrument.

Furthermore, results on the difficulty index showed that all questions in the HOTS-QE instrument were found to have moderate difficulty as the difficulty index values ranged between 40.74% to 70.00%. This suggests that the difficulty

Table 7: Results for discriminant index, difficulty index, and Cronbach's alpha coefficient

Question	*T*	*Discriminant Index (%)*	*Difficulty Index*	*Interpretation of Difficulty Index*	*Cronbach's Alpha*
1	2.65	31.11	57.58	Moderate	0.79
2	2.63	35.19	56.48	Moderate	
3	7.79	53.33	68.89	Moderate	
4	6.03	37.04	38.89	Moderate	
5	4.44	53.33	60.00	Moderate	
6	3.40	38.89	66.67	Moderate	
7	2.95	30.16	43.65	Moderate	
8	6.04	63.89	65.28	Moderate	
9	4.32	55.56	70.00	Moderate	
10	5.29	38.89	63.89	Moderate	
11	0.46	6.67	52.22	Moderate	
12	2.28	27.78	65.74	Moderate	
13	2.50	22.22	40.74	Moderate	
14	7.82	64.44	64.11	Moderate	
15	6.47	66.67	64.44	Moderate	
16	2.73	44.44	66.67	Moderate	
17	2.79	37.78	61.11	Moderate	

level of these HOTS questions is appropriate and not extremely high to the point that it can halt students' capability to answer the HOTS questions (Zulnaidi, 2013).

It was also revealed that all questions in the HOTS-QE instrument had obtained a reliability value of 0.79, thus indicating high reliability (Chua, 2006). Results from the pilot study thus conclude that all questions in the HOTS-QE instrument are good and strong. Therefore, all items in the test instrument were retained and used in the actual study, with the exception of Question 11.

Discussion

This study had reported on the seven stages of developing a validated Higher-Order Thinking Skill Test Instrument on Quadratic Equations (HOTS-QE). The I-CVI mean validity for each item was above 0.80 and the overall S-CVI value was 0.98, thus confirming the content validity of the instrument. Content Validity Index is the most often used index in quantitative evaluation and is a method of empirically determining the validity of the instruments used thorough analysis of the collected data. This method is simple to administer, low-cost, time-saving, and simple to implement (Ping & Osman, 2019). Other studies such as the development of the Geometrical Measurement Skills Instrument (Nasser & Lian, 2021) also used the same analysis to measure content validity. The process of modifying the instrument according to the experts' recommendations was also necessary to improve its efficacy in measuring students' level of HOTS.

The Cohen's Kappa coefficient was used in this study to verify the domain-level accuracy of the HOTS-EQ instrument, which included applying, analyzing, and evaluating based on the Anderson and Krathwohl (2001) Taxonomic Model hierarchy. This was crucial because Cohen's Kappa coefficient is a consensus index of interrater agreement that was used together with the CVI to confirm that experts' agreement was not due to chance. Therefore, computing Cohen's Kappa coefficient ensures a better comprehension of content validity because it eliminates any chance of agreement. A good Cohen's Kappa coefficient implies that the instrument can consistently measure the corresponding domains over time. The HOTS-QE's acceptable level of stability can be attributed to the clarity, simplicity, and specificity of its questions (Beyera et al., 2020).

Data from the pilot study were analysed using the ANATES V4 software to measure the instrument's reliability from the measures of discrimination index, difficulty index, and Cronbach's alpha coefficient. Other studies such as the evaluation of mathematics instrument on students' achievement in relation to limit functions (Zulnaidi et al., 2020) also used similar analysis to measure content reliability. Findings from the pilot study indicate an acceptable reliability, subsequently suggesting the questions' stability and consistency if tested repeatedly among respondents with homogeneous characteristics.

Overall, identifying HOTS for problem solving within the topic of quadratic equations requires appropriate measuring tools or instruments. The aim of developing the HOTS-QE instrument in this study was to identify students' problem-solving knowledge and strategies to solve non-routine problems that revolve around everyday situations. The instrument was able to explore non-routine problem-solving steps (i.e., questions not commonly found in textbooks) performed by students across various levels of thinking. This is in line with the findings by Setiawan et al. (2021) who reported that tests containing higher-order thinking questions encourage students to think about the subject matter. Furthermore, some researchers are more interested in pedagogical approaches as well as teaching aids and tools for the topic of quadratic equations (How et al., 2022). The development of this instrument thus complements previous studies where it can facilitate the effort of gathering information regarding effective quadratic equations problem-solving strategies. The decision to adopt the APOS theory as the systematic knowledge guide in the instrument content development also provided an empirical description of the students' mental structure in the quadratic equation content (Cahyani & Rahaju, 2019). It is hoped that the use of such instrument can facilitate the effort of gathering information regarding effective quadratic equations problem-solving strategies.

Conclusion

Instrument development needs to be done with accurate and correct procedures in terms of source analysis, fundamental theories, as well as validity and reliability measures to ensure that the test instruments developed can be used repeatedly. A properly constructed instrument will certainly have no issues in measuring the variables under investigation. The validity and reliability assessment using content validation index, HOTS level accuracy using Cohen's Kappa coefficient, and the use of the ANATES V4 software to measure discrimination index, difficulty index, and Cronbach's alpha coefficient had shown that the Higher-Order Thinking Skill Test Instrument on Quadratic Equations (HOTS-QE) is a valid and reliable tool to measure the level of HOTS among secondary school students for the topic of quadratic equations.

One limitation of this study is that the HOTS-QE instrument can only be implemented if students have mastered the lower-order thinking skills like the remembering and understanding domains. Otherwise, the absence of these basic knowledge will halt the development of cognitive ability in achieving the mastery of HOTS domains. Furthermore, the following recommendations are made in light of these results. First, the HOTS-QE instrument can be further improved by integrating digital literacy skills such as the use of the Computer Algebra System (CAS) Graphical Calculator to solve quadratic equation problems. For example, students can determine the roots of a quadratic equation on a quadratic function graph using the Desmos software. This will not only assess their ability to answer HOTS questions but also their mastery of digital skills in producing effective ideas when solving quadratic equation problems.

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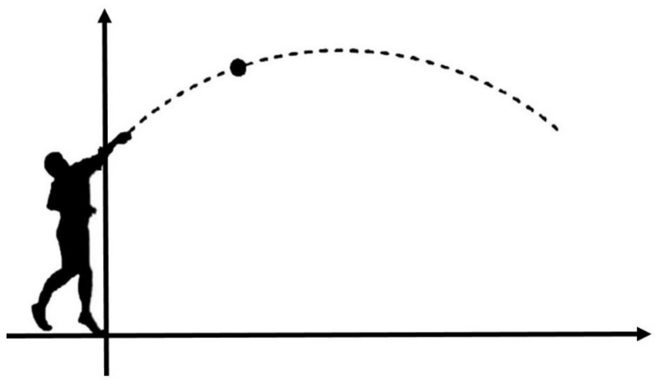
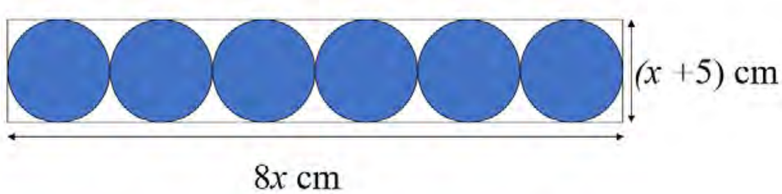
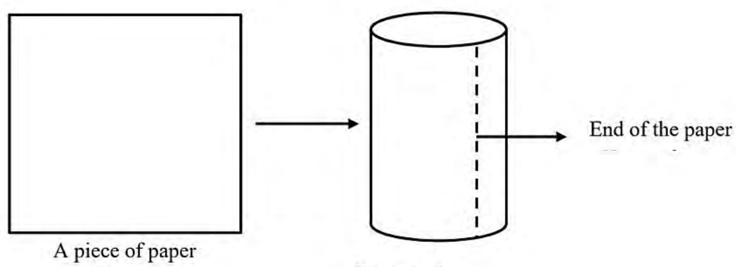
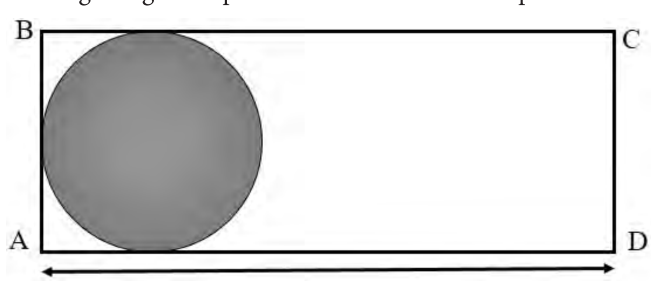
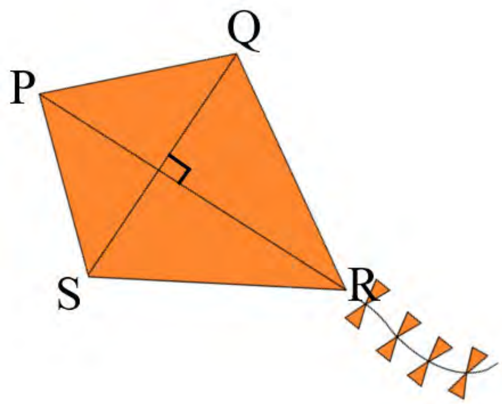
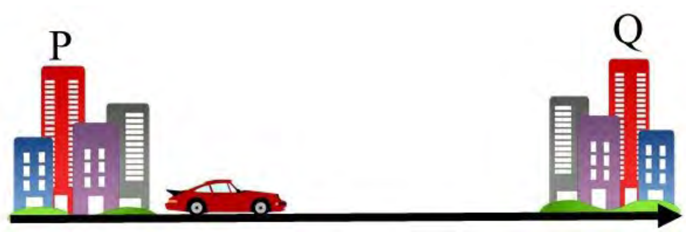
APPENDIX 1

HOTS-EQ INSTRUMENT TEST	
Write your answer in the space provided in the question paper. Show all important steps to solve each question. This will help you to get marks. You are allowed to use a non-programmable scientific calculator. The test time is **2 HOURS** only.	
No.	Question
1	The diagram below shows a student participating in a shot put competition during a sports event.  The shot put's motion can be modelled using the equation $y = -2x^2 + 7x + 15$, where *x* is the throwing distance in m and *y* is the height in m. If the distance of the shot put is more than 4 m, the student will represent his sports house. Determine whether the student will represent his sports house or not. Explain your answer.
2	Solve $2^{2x} - 5 \times 2^x - 24 = 0$.
3	Water flows into a tank at the rate of $(x+5)$ m^3s^{-1}. If the tank's capacity is 600 m^3 and it takes 2*x* m^3 of water to fill up the tank, (i) Form a quadratic equation representing time, in *x*. (ii) Find the time required to fill up the tank.
4	The diagram below shows a rectangular garden path. There are 6 pieces of round-shaped stepping stones of the same size built on the path.  Given that the surface area of the path is 0.24 m^2. (i) Form a quadratic equation representing the area of the path, in *x*. (ii) Find the diameter, in m, of each stepping stone.
5	Mr. Zulkifli is an architect. He needs to prepare a plan for the construction of a rectangular swimming pool. Given that the length of the swimming pool is 6 m more than its width and a lane with the width of 1 m is built around the pool. The area of the swimming pool including the surrounding lane is 72 m^2. (i) Form a quadratic equation representing the area of the swimming pool including the surrounding lane, in *x*. (ii) Find the length of the swimming pool.

6	Firdaus uses a quadratic formula to solve a quadratic equation. He substitutes the value in the formula correctly and obtains the following answer: $\frac{-5 \pm \sqrt{25 - 12}}{6}$ Re-write the quadratic equation that Firdaus is solving in the form of $ax^2 + bx + c = 0$. Note: (*a*, *b*, and *c* are integers)
7	An opened shoe box is 7 cm high and its length is 5 cm more than its width. If the total outer surface area is 500 cm^2, (i) Find the length and width of the box. (ii) Next, find the volume of the box.
8	Sasa is 4 years older than Azlie. The product of their ages is 12. How old is Sasa?
9	Amanda buys $(2x - 17)$ dictionaries that cost RM12*x* each. She pays 4104 dollars for all the dictionaries. (i) Form a quadratic equation representing the number of dictionaries, in *x*. (ii) Count the number of dictionaries bought by Amanda.
10	Solve the following simultaneous equations: $2x + y = 4$ $y^2 + 5 = 4x$
11	A piece of paper is rolled end to end as shown in Diagram 3 to form the curved surface of a cylinder. The length of the paper is the circumference of a circle for the cylinder, and is 2 cm longer than its width represented by *x* cm.  Diagram 3 If the area of the curved surface is 120 cm^2. (i) Form a quadratic equation representing the area of the curve, in *x*. (ii) Calculate the length of the paper.
12	The diagram below shows a rectangular garden plan ABCD with a circular pond.  Given that the radius of the pond is *x* cm and the area of the whole garden is 40 m^2. (i) Form a quadratic equation representing the total area of the park, in *x*. (ii) Calculate the length, in m, of CD.
13	The multiplication product of two consecutive odd numbers is equal to 323. Given the smaller odd number is $2n + 5$. (i) Form a quadratic equation representing the multiplication product of two consecutive odd numbers, in *n*. (ii) Calculate the larger odd number.

14	The figure below shows a kite PQRS. The diagonal lengths of PR and QS are $(3x+5)$ cm and $(2x-8)$ cm respectively.  (i) Given that the area of the kite PQRS is 550 cm^2, form a quadratic equation for the area of the kite PQRS in x. (ii) Next, calculate the length of the diagonal PR.
15	Farikh Enterprise wants to build a rectangle playground. The length of the playground is 15 meters longer than its width and the area of the playground is 250 m^2. (i) Form a quadratic equation representing the area of the playground in x. (ii) Calculate the perimeter of the gate to be built around the playground.
16	A car travels at a speed of $12t$ km/j from City P to City Q.  If the car travels for 720 km in $(t + 4)$ hour: (i) Form a quadratic equation representing the travelling time of the car, in t. (ii) Calculate the time duration taken for the car to travel from City P to City Q.
17	A famous ancient Chinese book called "*Jiu Zhang Shuan Shu*" which means "Nine Chapters on the Art of Mathematics" contains the following problem. "The height of a rectangular door is 6.8 units more than its width and the length between two opposite corners is 100 units. Find the width of the door." Solve the problem above using the quadratic equation concept.