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Validation of Mathematics Test to Assess Polytechnic Students' Problem Solving

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Abstract

Mathematics education and problem-solving are inseparable due to the significance of solving problems with educational implications. This study aims to describe the process of developing and validating a test that measures problem-solving skills in Integral Calculus. This study is done to identify traces of the intended strategy in the answers, style, and quality of the student's responses. Data collection techniques were carried out through mathematical tests using problem-solving questions. The difficulty index, discrimination index, and reliability were calculated to analyze the data for each problem-solving instrument. Based on expert reviews, evaluations, and data analysis tests, five valid problem-solving instrument items with a discrimination index greater than 0.30 and Cronbach's alpha reliability greater than 0.60 have been developed. Therefore, it can be concluded that the developed maths test questions can enhance the problem-solving skills of Ibrahim Sultan Polytechnic students.

Keywords: Problem Solving, Mathematics Test, Validity, Reliability

Abstrak

Pentingnya pemecahan masalah yang berdampak pada pendidikan membuat pendidikan matematika dan pemecahan masalah tidak dapat dipisahkan. Penelitian ini bertujuan untuk mendeskripsikan proses dalam mengembangkan dan memvalidasi tes matematika yang mengukur pemecahan masalah dalam Kalkulus Integral. Hal ini dilakukan untuk melihat jejak strategi yang dirancang dalam jawaban siswa, gaya, dan kualitas jawaban mereka. Teknik pengumpulan data dilakukan melalui tes matematika menggunakan soal pemecahan masalah. Analisis data untuk setiap instrumen pemecahan masalah dilakukan dengan menentukan indeks kesulitan, indeks diskriminasi dan reliabilitas. Berdasarkan hasil penilaian para pakar, evaluasi, dan uji analisis data, telah dihasilkan 5 item instrumen pemecahan masalah yang telah valid dengan indeks diskriminasi lebih besar dari 0,30 dan reliabilitas alfa Cronbach di atas 0.60. Sehingga, dapat disimpulkan bahwa soal tes matematika yang dikembangkan dapat meningkatkan kemampuan pemecahan masalah siswa di Politeknik Ibrahim Sultan.

Kata kunci: Pemecahan Masalah, Tes Matematika, Validitas, Reliabilitas

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INTRODUCTION

Nonroutine problems can be extremely active problems that sometimes call for students to work together to solve them (Seacrest, 2011). Selden et al. reported that even above-average calculus students often struggle while solving nonroutine problems. The inability to answer nonroutine questions is studied by Faizatulhaida, Azlina, and Hajar (2017) stated that students are unable to choose the right techniques in problem solving for Integral Calculus. It has been found that many of the questions involving problems cannot be solved by polytechnic students, because they do not understand the question and cannot understand the symbols used. This causes respondents to be unable to convert problem sentences to symbols or mathematical forms, and to identify necessary operations or strategy.

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It supported by Ghazali and Rosli (2017) stated that students were found to be unable to solve the question in the form of problem solving. They do not seem to understand and master the concept of finding a wide range of curves in the process of estimation (Cheng, Hassan, & Mustafa, 2017). Hence, this study contributes to mathematics education by expanding the knowledge base concerning the nonroutine problem in Integral Calculus and it also contributes to the way to enhance the difficulties.

With the importance of problem solving that inevitably impacts education, mathematics education and problem solving are undeniably inseparable. Looking at the urgent need to cultivate problem solving is by creating an active and engaging learning environment where students are more likely to make connections and see the value of the content (Hohmann & Grillo, 2014). Students are expected to develop new knowledge and skills through problem solving process, as well as apply various math problem solving strategy in different contexts. This demand has forced educators to introduce initiatives to assist students who do not have higher order thinking and problem solving skills. To achieve MOE intentions, one of the challenges that teachers need to address is the emphasis on problem solving. Malaysian Education Blueprint (MEB) 2013 – 2025 has recommended focus is given to problem solving.

Another indicator of problem solving in Integral Calculus is seen in the volume of rotating objects (Fatimah and Yerizon, 2019). Students have difficulty with questions that involve the integration of trigonometric functions and applying integration to evaluate plane areas. The students seem to focus more on the procedural aspects of integration than on the conceptual aspects. They generally lack both conceptual and procedural understanding of integration (Kiat, 2005). Respondents fail to understand the general requirements of the question, which caused them to fail to make the next transformation. 54.4% of the respondents agreed that aspects of comprehension such as vocabulary, response patterns, inability to differentiate data and lack of self-confidence would result in errors in problem solving (Rohani, Riyan, & Effandi, 2014).

Students' difficulties were due to the passive activities in the class (Khalid, Alias, Razally, & Suradi, 2015). It does not stimulate learning and neglects the thinking skills and problem solving ability. Besides, difficulty in understanding problem solving is due to the absence of critical thinking. Students lack knowledge in assessing critical thinking during problem solving. Even Polya (1973) argues that the real ability to solve problems lies in the idea of devising a solution plan which requires critical thinking skills. Hence, there is a need to study critical thinking infused through a learning strategy to enhance problem solving. In problem solving, students employ critical thinking skills in the analyses of problems and applications of previously learned concepts. As problem solving is compliment with critical thinking, this is important to embed this skill. This study aims to describe develop and validate mathematics test to assess Polytechnic students' problem solving.

METHODS

Sample for Students

For the pilot study, 35 students enrolled in the Engineering Mathematics 2 course from the polytechnic selected. The number of 30 students is sufficient to determine the reliability of an instrument (Chua, 2011). Pilot sample sizes do not need to be large but sufficient to meet the purpose of competent early discussion of the test. The pilot studies have to be carried out on the participants of the study which is equivalent to the actual study covering the aspects of the location, and the profile of the study participants. It provides an excellent opportunity to uncover such problems ahead of time, minimizing the need to adopt procedures or to develop contingency plans on short notice when the larger study is being conducted (Viechtbauer *et al.*, 2015). Pilot study students are engaged in the pre-test and post-test.

Sample for Experts

The study instrument is reviewed by three experienced experts E1, E2, and E3 (see Table 1). They were requested to review the problems in the preliminary investigation, pre-test and post-test. The main purpose of the mathematics was initially explained to them, and subsequently, they were requested to review each item about to the overall purpose of the test.

Table 1. Experts for mathematics

Experts	Information of the Experts
E1	• Professor • 38 years of working experience • Phd (Mathematics Education) • Professor at IPTA
E2	• Professor • 30 years of working experience • Phd (Mathematics Education) • Professor at IPTA
E3	• Associate Professor • 28 years of working experience • Phd (Mathematics Education) • Associate Professor at IPTA

Instrumentation

Quantitative data are obtained from mathematics before and after learning of Integral Calculus for the pilot group. The mathematics were known as pre-test and post-test. Before teaching Integral Calculus, the pre-test was given to the students, while the post-test was taken at the end of the intervention. The process of developing the problem solving instrument is divided into the requirements study and the development illustrated in Figure 1.

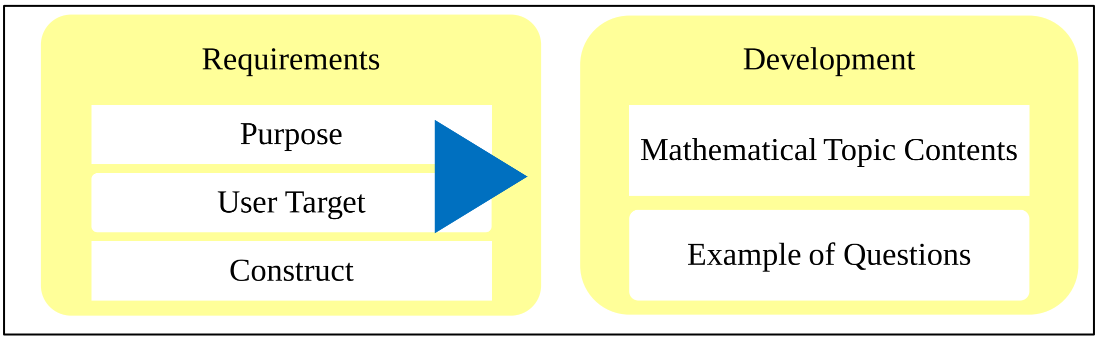

Figure 1. Flow chart of the development of mathematics

Requirements of Mathematics

The requirements are to determine the purpose and targets of the mathematics as described as follows:

Purpose of Mathematics

To see the traces of designed strategy in students' answers, the style, and quality of their answers were important. Several major reasons led to the development of mathematics. First, to see the current review of the critical thinking process in Integral Calculus.

Students' answer sheets for their problem solving written solutions in pre-test and post-test of Integral Calculus were evaluated to investigate their achievement qualitatively. The researcher reviewed Polytechnic Mathematics syllabus, books and considered the literature studies. The test measuring the methods used by Polya (1973) namely understanding, devise a plan, carry out the plan and look back. Each problem should be solved with the complete solution to determine the marks of the students.

The User Targets

The developed instruments for mathematics tests are implemented for polytechnic students enrolled in Engineering Mathematics 2 subjects which consist of the Integral Calculus topic.

The Initial Information for Defining Constructs

Mathematics are in the form of nonroutine problem solving and real life application problems. Solving nonroutine problems involves using mathematics in often unfamiliar ways to solve problems that are both mathematical and in a real-life context (Spinato, 2011). The explorations involve using a wide range of strategies to solve unfamiliar tasks, as well as developing the processes of analysing, reasoning, generalizing and abstracting (Atteh *et al.*, 2017). Learners are placed in the active role of problem solvers by being confronted with nonroutine problems (Chirinda, 2013). Nonroutine problems that call for the application of knowledge and involve unexpected and unfamiliar solutions are often classified as problematic questions (Boadu, 2014). Solutions to nonroutine problems often require some level of conceptual knowledge in addition to any procedural knowledge (Bajrachrya, 2014). Familiarity with nonroutine problems may help enhance students' mathematical self-efficacy and reduce math and test anxiety (Seacrest, 2011). Accordingly, it is important to familiarize students with this kind of problem.

Development of Mathematics

Development begins briefly mathematical topic content in mathematics, methods of scoring and examples of problems.

Mathematical Topic Content in Mathematics

Development of the Integral Calculus problem solving instrument is based on the mathematical topics in the polytechnic syllabus, for the course Engineering Mathematics 2 and particularly in the Integral Calculus topic. It is developed to assess the student's ability to answer nonroutine problem solving, which requires critical thinking process namely interpretation, analysis, inference, evaluation, explanation and self-regulation. To be decision makers, someone must have critical thinking (Helsdingen *et al.*, 2011) and in this situation, it was evaluated by utilizing nonroutine problems. Polya (1997) also added that nonroutine problems should also be included in teaching to develop critical thinking. Nonroutine problems require that the skills and knowledge of individuals are used in extraordinary ways (Saygılı, 2017). Therefore, nonroutine is very suitable for use in this study.

The basis for the development of this instrument is from the previous examination question and is integrated with life application. Some are modified from Barnett et al. (2012) Mathematics are consist of pre-test and post-test, covering the same topic, which is Integral Calculus with the same arrangement but a different statement, number, and function. All items in this instrument are constructed and adjusted based on the Test Specification Table (TST) and within the application domain.

TST contains important data on the contents of the test and thus can further elevate the level of objectivity and validity of the content. It increases the degree of authenticity of the content and information about the constructs that will be measured (Gregory, 2011). The purpose is to give information about the constructs that will be measured. Furthermore, it improves the validity of teacher-made tests and can improve student learning as well and provide guidance to lecturers on the syllabus that needs to be taught and the objectives to be achieved by the students. In addition, it ensures the distribution is subject to the sub-topic and balanced and systematic.

Nonroutine Problem Solving

It is common to know that this nonroutine problem involves more complex mathematical reasoning. Problem solving process cannot be memorised, it requires a set of systematic activities with appropriate strategy planning and methods. Nonroutine problems can be extremely active problems that sometimes call for students to work together to solve them (Seacrest, 2011). Nonroutine problems are the type of problems where students are faced with an unfamiliar problem situation without an apparent solution path (Kuzle, 2011). It is chosen as a means to elicit and develop students' problem-solving competencies (Kilpatrick, 2014).

Nonroutine problems should also be included in teaching to develop critical thinking and creative skills (Polya, 1978). Nonroutine problems are more efficacious in developing and accessing students' problem-solving skills (Polya, 1962). Nonroutine problems require that individuals use their skills and knowledge in unusual ways (Saygılı, 2017). However, students generally fear the idea of solving nonroutine problems because these problems are usually non-standard, involving unexpected and unfamiliar solutions (Yeo, 2004). Nonroutine problems focus on a deepening of understanding mathematical concepts and the problem-solving process (van Velzen, 2016).

Example of Problems

Pre-test and post-test instruments are developed about the Integral Calculus topic. The pre-test and post-test contain five problem solving problems in the form of nonroutine problems and related to real life applications. The problems are constructed from the nonroutine problem because this type of problem is infused with the application element. Nonroutine problems require that one or two of problem solving strategy, skill, and knowledge of individuals are used in extraordinary ways (Saygılı, 2017). Among the aims of application in nonroutine problems is to inculcate student interest in its use in life, to build attitude and appreciation, strengthen learning, stimulate critical thinking, seek reason or explanation. In the designing of the tests, the researcher prepared a general form of problems based on the critical thinking process. It was to see whether there were any changes in the students' scores and achievement in problem solving. Measuring the changes in students' marks from pre-test to post-test within and between the two groups was the main goal of the tests.

Data Analysis

The percentage value of mathematics that has been assessed by an expert was evaluated using the Percentage Calculation Method (PCM) method (Setambah, Tajudin, Adnan, & Saad, 2017). This was evaluated using the following formula:

$$\text{Content Validity Level} = \frac{\text{Total Expert Score (X)}}{\text{Total Maximum Score}} \times 100$$

The total expert score is the score that assesses the scale of the questionnaire to be calculated. The total expert score is then divided by the total maximum score. The questionnaire uses a 4-point scale consisting of 10 items, and the maximum score for each item is 4. The total maximum score is calculated based on the product of the number of items with a maximum score. Then, the value will be multiplied with 100. As a result, those values are called as content validity measurement achieved by mathematics. On the other hand, the reliability value of the mathematics was calculated based on statistics by calculating Cronbach's alpha coefficient.

RESULTS AND DISCUSSION

In addition to face validity and content validity, construct validity was also performed for the mathematics by performing item analysis. Item analysis for each mathematics tests instrument was performed by determining the difficulty index, discrimination index and reliability.

Validity

Specifically, the content experts were requested to review each item based on the following criteria in Table 2.

Table 2. Validation for mathematics

No	Items	Expert		
		1	2	3
1.	Questions is in the form of problem solving	4	4	4
2.	Problem solving should have criteria which is nonroutine	4	4	4
3.	Problem solving is related to application in real life.	3	3	4
4.	Problem solving require critical thinking skills to solve it.	3	4	3
5.	The schema is correct and complete,	3	4	3
6.	The code for each solution is suitable with the rubric	3	3	3
7.	The marks are suitable with each step.	3	3	3
8.	Time allocated for is appropriate.	4	4	3
	Total	27	29	27
	Content Validity Achievement (100%)		86.46	

Table 2 shows the content validity measurement for the mathematics. The mathematics test has achieved the content validity of 86.46% and the value is above 70%. Based on the result, contents in the mathematics are considered of good validity. The experts reported that most of the mathematics items were appropriate and relevant to measure the problem solving in Integral Calculus. They had also given useful feedback on a few of the items that they thought required revision. Next, comments and suggestions for the improvement of the mathematics provided by experts have been shown in Table 3. In line with the comments, all the necessary revisions were made.

Table 3. Experts' comment and suggestion and improvement action for mathematics

Expert	Comment	Suggestion	Improvement
E1	Problem solving must clear either contain: (a) The nonroutine problem	Critical thinking from Facione since it has been established	Problem solving is modified to nonroutine problems
	(b) The language, information and meaning need to translate into numeric equation (c) Requires multistep skills and strategy	For pre-test should be a test for critical thinking to checks for the assumption that the group level in critical thinking.	Problem solving is modified which require critical thinking process in each step
E2	The direct question problem is a typical calculus problem.	The problem for problem solving should be the following criteria: (a) nonroutine (b) ill-defined (c) non-structured (d) realistic	Problem Solving is modified to nonroutine problems and in real life applications
	0.5 marks is not suitable	1 mark is given for each work involved	All marks is given according to rubric
	The language used is quite high, it is feared that the student cannot understand it.	Put a picture on the question	Language is modifying at a lower level so students can understand the question
	In some questions, it is difficult to find the traces of using critical thinking in students' answer for the questions.	Specify this question is adapted to the adopted, or originality from another org or modified	Each critical thinking process is deeper modified
E3	The picture will capture the students' attention and help them to understand the questions better.	Put the picture in the pre-test	Picture have been put in the pre-test
	The pre-test and post-test questions testing the same subtopics and concepts but in the different situations.		
	The given problem solving question give students a better understanding of how to relate their lives to science and integration.		

Next after evaluation by the evaluation panel, instrument pilot study conducted on a sample of students comparable with those of the actual study. A pilot study was conducted using pre-test in September until October 2018 to over 30 students in the polytechnic which is equivalent to the study subjects which is the second semester student who enrolled in subject Engineering Mathematics 2. The pilot study was carried out to determine the construct validity and reliability of the instrument. In addition to the face validity and content validity, construct validity was determined by performing analysis items. In this study, the difficulty index and discrimination index are used to determine the construct validity of the instrument items. Item analysis for each instrument of problem solving performed is described in the next subsection.

Difficulty Index

To determine the level of item difficulty for mathematics, the item difficulty index is used. The purpose of the difficulty index is to confirm the concepts that need to be modified, that is when a lecturer finds the question of questioning cannot be answered by a large number of students. The difficulty index is of particular relevance because of the more difficult the item, the greater the tendency for the student to commit errors (Veloo, Krishnasamy, & Abdullah, 2015). Next, identify and report students' strengths and weaknesses for the subtopics tested. For subjective items (essays); whose value is taking values 0, 1, 2, 3, …; index the difficulty can be calculated as average mark ratio (mean score) to a full range of scores such as following (Nitko, 2004). As a result of the pilot study of the items, the difficulty index is described in Table 4.

$$\text{Difficulty Index} = \frac{\text{Average score}}{\text{Range of Full Marks}}$$

Table 4. Difficulty index value for mathematics

Instrument	Item	Difficulty Index
Pre-test	1	0.499
	2	0.572
	3	0.476
	4	0.458
	5	0.403
Post-test	1	0.443
	2	0.549
	3	0.479
	4	0.423
	5	0.353

Table 4 shows that the construct validity of the instrument mathematics test has difficulty index between 40 percent and 60 percent. It shows that the entire item meets the validity requirement (Nitko, 2004). Thus, the mathematics is suitable for the actual study.

Discrimination Index

Good questions will be able to discriminate between those with the low capability and high capability. The index used to determine the difference in the ability of this is the discrimination index. To compute the item discrimination index, the item scores of groups of high and low scoring students were selected (Tiruneh *et al.*, 2016). Discrimination index determines whether a respondent who had done well on particular items had also done well in the whole test (Ghadi *et al.*, 2013). The size that determines how far an item it can distinguish between the exam candidates who owns or controls the knowledge tested with other candidates who are not in control that knowledge. Item discrimination implies that poor-performing students should not be expected to score well, and high- performing students should be expected to do well (Brits, 2017).

To compute the item discrimination index, student answer sheets are prepared in advance by the percentage of correct order and divided into three groups, namely the achievement of high, medium and low. The discrimination index formula is as follows. As a result of the pilot study of the items, the discrimination index is described in Table 5.

$$\text{Discrimination Index} = \frac{\text{Mean Upper Group} - \text{Mean lower Group}}{\text{Score Maximum item}}$$

Table 5. Discrimination index value for mathematics

Instrument	Item	Discrimination Index
Pre-test	1	0.363
	2	0.33
	3	0.355
	4	0.322
	5	0.357
Post-test	1	0.302
	2	0.356
	3	0.454
	4	0.344
	5	0.357

Table 5 shows that the construct validity of the instrument mathematics test has a discrimination index greater than 0.30, indicating that items have valid validity (Nitko, 2004). Hence, the mathematics is convenient for the actual study.

Reliability

Cronbach alpha value is sought to evaluate the reliability of the research instrument (Daud, Yunus, & Yusor, 2017). The value of alpha coefficient exceeds 0.7 is much suggested by most researchers (Sekaran & Bougie, 2016). Cronbach value exceeding .70 indicates good internal consistency for new instruments. Cronbach's alpha coefficients are used to determine the internal consistency value of each synthesized factor and all items. This means that an individual will get the same score from an instrument if the ability of the individual is consistent or the trait to be measured does not change even though measured over and over with the same instrument (Abdullah and Wei, 2017).

In statistics, Cronbach's alpha, α is the internal consistency coefficient because it increases as the inter-correlations among test items increase (Chung, 2015). Furthermore, Piaw (2011) states the internal consistency method is a method that evaluates the internal consistency of the instrument by finding the correlation value between the scores of each item in the test with the total score for all items in the test (test index score). Data were analysed using SPSS to obtain reliability through Cronbach Alpha test.

Table 6. Cronbach alpha value for mathematics

Instrument	Cronbach alpha
Pre-test	0.995
Post-test	0.714

Based on Table 6, the findings show that the distribution of items after the pilot study yielded Cronbach Alpha reliability test results for all four instruments above 0.60, which concluded that the items had good internal consistency and reliability (Pallant, 2013). Accordingly, the item mathematics test that has been developed can be used for the actual study as it has validity and reliability as required.

CONCLUSION

This study produced 5 items on the mathematics test using problem solving. Based on the results of the expert reviews and the validation test, it shows that the mathematics test questions are valid evaluation instruments. The content validation achievement was 86.46% was found perfect obtained from 3 raters. The mathematics tests was found to be of appropriate difficulty index which in the range of 40% and 60%. Hence, the mathematics is convenient for the actual study with the discrimination index greater than 0.30 and cronbach alpha reliability for all four instruments above 0.60. In addition, the developed maths test questions can enhance the problem-solving skills of Ibrahim Sultan Polytechnic students.

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