The development of an instrument to explore non-routine problem solving strategies among mathematics education students

R M Bambang S, Salasi R, M Hasbi and Mardhiah MZ
Syiah Kuala University, JL. Tgk. Chik Pante Kulu No 5, Banda Aceh, Indonesia, 23111
E-mail: bambang_radenmas@unsyiah.ac.id

Abstract. This research aimed at describing the validation results of instrument development to explore the non-routine problem solving strategies, especially the non-routine strategy assignment and interview guidelines. The validity of the assignment instrument is viewed from the aspect of accuracy, strategic direction, cognitive level, scope of the knowledge, and legibility of the problems. The interview guidelines instrument is evaluated by the ability to disclose the strategy, the nature of the question by being exploring and not guiding, and the clarity of the students’ response. This study is part of the broader development research. The subjects were Mathematics Education students of Syiah Kuala University. The research instrument was a validation sheet about non-routine problem solving strategy and interview guidelines. Data were collected by obtaining expert’s opinion on the content and construct validity of the non-routine problem solving strategies assignment instrument, while the data collection for the trial was conducted through the task-based, semi-structured interview. Expert validation data then was analyzed by reviewing thoroughly the experts’ suggestion and opinion on the instrument validation, while the result of the trial is analyzed by describing the emerging strategies from student’s response to the given problems. The validation result of instrument development indicates that the instrument and interview guidelines are applicable in order to explore strategies used by students in non-routine problem solving.

1. Introduction
Problem solving is one of the cognitive activity procedures used in everyday life [1]. Gagne [10] asserts that solution finding is high-level thinking process. Thus, problem solving is the process of thinking that requires the implementation of procedures or strategies in mathematical problem-solving activities. The success of an individual in obtaining the solution of a problem is influenced by the knowledge, skills, and the ability to link the knowledge structure in the mind [10], and the process of using those strategies in problem-solving [3].

Findings from a study [4] in non-routine problem-solving strategies at first-year students show that students are generally successful to apply strategies in problem solving. The success of a student in carrying out non-routine problem solving activities is also influenced by the problems encountered. One question may become a problem for student A, which is not necessarily a problem for student B, or vice versa. Therefore, developing non-routine problem-solving instruments and interview guidelines are considered important.
2. Methods
This research is a development research using descriptive approach [7]. The sample was students of Mathematics Education of Syiah Kuala University. The data were collected by (1) distributing validation sheet to assess the content and construct of the non-routine problem-solving strategy, and validation sheet to assess the content and construct of the interview guidelines to 2 validators for assessing the content and construct aspects. A validator is an expert and Doctor of Mathematics education, (2) enrolling the test of the non-routine problem-solving strategy assignment instrument towards 15 students, at the same time, the interview guidelines instrument was tested towards 2 students based on the completion of the assignments. Data were collected using an expert validated sheet for non-routine problem-solving strategy assignment and an expert validated instrument of the interview guidelines. The raw data were analyzed by reviewing and revising the results from the assessment towards the problems in the problem-solving strategy task and the questionnaires in the interview guidelines; while the test results from the trial were analyzed by examining and interpreting the strategies that emerged in student’s attempt to solve the given problems.

3. Results and discussion
The result of this study comprises the results from the development of non-routine problem-solving strategy instrument and the interview guide instruments. The result from the instrument development is in the form of the validated instrument and the tested instrument of problem-solving strategy task and interview guide. Results from the development of the two instruments are presented as follows:

3.1 Results of Validation and Testing of Non-Routine Problem-Solving Strategy Assignment
Experts’ validation was performed to evaluate the contents validity. Expert validation results are used as a basis for the revision and refinement of the research instruments. The revised instrument then used to explore the strategies students used in solving non-routine mathematical problems [5,12]. The validators in this study consist of two mathematics education experts. Based on the suggestions and comments from the validators, several revisions and improvements were made as the first draft, which later compiled into the second draft.

| No | Submitted | Revision |
|----|-----------|----------|
| 1  | A square root of a swarm of bees from its nest heading to the west, while the 5/7 parts of this swarm turned eastwards. Whereas 4/3 of the bees that go eastwards minus 15 multiplied by 7 yields 15. How many bees present at first? | A square root of a swarm of bees from its nest heading to the west, 5/7 of this swarm turned eastward, whereas 4/3 of the bees that go eastwards minus 15 multiplied by 7 yields 15. How many bees present at first? |
| 2  | Santi and Tini run along a circular trajectory. Both begin to run at the same time from point P, but take the opposite direction. Santi ran 1 1/2 times faster than Tini. If PQ is the center line of the circle path and both meet for the first time at the point R, determine how much ∠RPQ?. | Santi and Tini ran along a circular trajectory. Both begin to run at the same time from point P, but take the opposite direction. Santi ran 1 1/2 times faster than Tini. If PQ is the center line of the circle path and both meet for the first time at the point R, determine how much ∠QPR? |
| 3  | Mr. Ali has a water tank to fill in the reserve water. The water tank has an inverted cone with circular top which radius r meters and width h meters where the length of the basis radius is a half of the cone height. If water is pumped into the tank at a rate of 2m³/min, determine the rate of water level increase at a depth of 3 meters. | Mr. Ali has a water tank to fill in the reserve water. The water tank has an inverted cone with circular top which radius r meters and width h meters where the length of the basis radius is a half of the cone height. If water is pumped into the tank at a rate of 2m³/min, determine the rate of water level increase at a depth of 3 meters. |

The non-routine problem solving assignment sheet consists of 3 questions. The items in the non-routine problem solving strategy sheet related to the concept of numbers, algebra and geometry, and analytic calculus in the form of illustrated questions. The preparation of this non-routine problem
solving assignment begins with developing the main point needed for the assignment. This main point comprises the strategies that may be used by students in solving problems through Polya’s four steps, which is conformed on how the instrument was assembled [4,11]. Furthermore, two mathematics education experts validated the non-routine problem solving strategy assignment sheet. The validator assesses and provides inputs on the validation sheet. The results from the assessment of the two validators can be seen in Table 1.

Table 1 shows the result from the revision of the assignment based on the suggestion from the validator. In the first item, both validators suggested that the word "while" to be omitted. Next, the second item, the two validators also provided suggestions on the question to determine how much \( \angle RPQ \), changed in to question to determine how much \( \angle QPR \)?, in the third item, the first validator does not give suggestion, but the second validator provides suggestion on the writing of the symbol of "r "And" h ". The validation results show that the non-routine problem solving strategy assignment is accurate, divergent, liable, broad knowledge coverage, easy to understand, cognitive level appropriateness, and feasible to use after revision. Thus, the assignment instrument can be used to explore the strategies that might be used by students in order to solve the non-routine problem. [6]

The test to assess the instrument was enrolled on March 24, 2018 towards 15 third-year students of Mathematics Education Program. One of the student works of the non-routine problem solving strategy assignment as shown in Figure 1, 2 and 3.

![Figure 1. Student answer to question number 1](image-url)
Figure 1 shows the student used a compass drawing to understand the problem [6], and then write down the known and questioned data correctly, the student then creates the model and continue to solve the model. The student completes the model by using the backward strategy by multiplying the two segments by 1/7 then summing by 5 then multiplying the two segments by 21/20 then rooted by two to obtained solutions. From this student work, it shows that problem 1 contains various strategies to gain its completion. [3], completed sequentially, with drawing illustrations [4], using rules to obtain solutions, and showed to be a correlation to the cognitive level of students. Based on the subject's answer to question 1 and the instrument assessment indicators of non-routine problem-solving tasks it can be concluded that the task of non-routine problem has various settlement strategies, corresponded to the cognitive level of the student, and the knowledge coverage is only related to the numbers. Thus, question 1 indicates a non-routine problem that has strategies in progress.

![Figure 1. Student answer to question number 1](image1.png)

In figure 2 the student makes the illustration with complete and correct data [6], but there was an error in determining the speed equation [13]. To complete the task student used trial and error strategy, but fails to get the solution. The student work shows that problem 2 has various strategies to offer its solution. [3] Although drawing of illustrations was correct, the student failed to optimize the strategy [4] by miss calculating the speed equation. Based on the subject's answer to problem 2 and the instrument assessment indicators of non-routine problem-solving tasks, it can be concluded that the subject completed the task of non-routine problem by trial and error (only one strategy), knowledge coverage including the distance, speed (physics), geometry, algebra, and student cognitive level. Thus, problem 2 indicates a non-routine problem that has strategies emerged while solving it.

![Figure 2. Student answer to question number 2](image2.png)
In figure 3 the student creates a cone illustration along with the data, and then creates symbols of the tube size, generates important data from the question information, then creates an equation showing the relationship between volume and height of the tube, uses a similar triangular image to create the equation relationship between the radius and tube height, models the tube volume relationship with tube height, then calculate the speed of water over time using derivative rules. From this student work, it shows that problem 3 contains various solving strategies [3], [9] completed sequentially, drawing illustrations [4,6], knowledge coverage covering geometry, algebra, derivative (differential), and appropriate with student cognitive level [5]. Based on the subject's answer to the problem 3 and the instrument assessment indicators of non-routine problem-solving tasks, it can be concluded that the task of non-routine problem has various coping strategies, broad knowledge coverage, and cognitive level conformity. Thus, problem 3 indicates a non-routine problem that has strategies in progress.

3.2 Results of Validation and Interview Testing Instrument

The interview guide instrument contains questions-statements to explore the process of thinking about the use of strategies in solving non-routine problems of students which viewed through Polya steps, namely: understanding problems, planning, executing and checking results. Questions that are compiled on the interview guide are key questions which could be developed during the interview. This is to adapt with the student answer or response to the question. The items in the interview questions are consist of (1) the stage of understanding the problem: what is understood from the problem, how to understand and why to use it, (2) to plan: what should be done to solve the problem, how, why use it? (3) to solve: what should be made to get the solution, how to get the solution, why use it that way? (4) check the results: how to check the certainty of the solution obtained, how to check it, why use it that way? [11], [12] It is in accordance with consideration [2] that semi-structured interviews are used to explore the thinking process in solving problems by reading problems, explaining what is understood, explaining what strategies or knowledge they possess, explaining how to obtain solutions, and what should be done to check the results.
The items question in the interview guidelines which have been developed is further validated by 2 mathematics education expert validators using a validation sheet. Validators assess and make suggestions in the interview validation sheets. The results of the assessment of the two validators are shown in Table 2.

**Table 2.** The result of validation of contents and constructs of interview guidelines

| No | Interview Guideline Instrument | Score          | Validator 1         | Validator 2         |
|----|--------------------------------|----------------|---------------------|---------------------|
| 1  | Indicator completely described | Partially describe | Partially describe |                     |
| 2  | Ability to reveal strategies in non-routine problem solving | Good | Very good |                     |
| 3  | Open question                  | Open           | Open enough         |                     |
| 4  | Suitable with student cognitive level | Yes | Yes |                     |
| 5  | Triggered, not guided          | Good           | Good                |                     |
| 6  | Multiple interpretations       | No             | No                  |                     |

Table 2 shows the validation result of the interview guideline instrument is eligible to be used with minor revisions based on validators’ recommendation. Aspects of questions in the interview guide includes: 1) questions to trace the strategy in order to understand the problem, how to understand the problem, why use it, 2) the strategy of planning the settlement, that is how to plan, why use it, 3) the strategy of implementing the problem solving, that is how to solve it, why use it, 4) strategy to check results, that is how to check the solution obtained, why use it that way. The validation results of the two validators to the interview guidelines show that the interview questions; has no direct mention of the indicators at each stage, has the power of disclosing strategies in non-routine problem solving, in the form of open questions, conforms with the cognitive level of students, are in the nature of digging and not guiding, and does not lead to multiple interpretations. Thus, the interview guideline is applicable to explore strategies used by students in non-routine problem solving.

**4. Conclusion**

Based on the results of research and discussion, it indicates that the development of the problem solving strategy assignment instrument and the interview guideline instrument to explore the strategies used in problem solving is viable to be used. This article develops task instruments and interview guides to explore non-routine problem-solving strategies related to number theory, algebra and geometry and calculus, we strongly suggest to explore other materials in mathematics. We recommend testing non-routine problems on college students in order to gain a certain cognitive level in solving problems.

**Acknowledgments**

We thank Syiah Kuala University for providing the senior lecturer research grant funding, contract number 288/UN11.2/PP/PNBP/SP3/2018.

**References**

[1] Aljaberi N M 2015 University Students’ Learning Styles and Their Ability to Solve Mathematical Problem *International Journal of Business and Social Science* **6** 1

[2] Angateeah K S 2017 An Investigation of Students’ Difficulties in Solving Non Routine Word Problem at Lower Secondary *International Journal of Learning and Teaching* **3** 1

[3] Aveu S & Aveu R 2010 Pre-service Elementary Mathematics Teachers’ use of Strategies in Mathematical Problem Solving *Prodia Social and Biheviorical Science* **9** 1282 Available online at www.sciencedirect.com
[4] Celebioglu B, Yazgan Y, & Ezentas R 2010 Usages of Non Routine Problem Solving Strategies at first Grade Level. *Prodia Social and Biheviorical Science* 2 2968 Available online at www.sciencedirect.com

[5] Docktor J & Heller K 2009 Robust Assessment Instrument for Student Problem Solving *Proceeding of the NARST 2009 Annual Meeting*

[6] Duru A Peker M, Bozkurt E, Akgitn L, & Bayrakdar Z 2011 Pre-service Primary School Teachers’ Preference of The Problem Solving Strategies for Word Problems *Prodia Social and Biheviorical Science* 15 3463 Available online at www.sciencedirect.com

[7] Frenkel J R 1990 How to Design and Evaluation Research Instrumen Educatioan McGrwa Hill Publishing Coy

[8] Isoda M dan Katagiri S 2012 *Mathematical Thinking: How to Develop it in the Classroom* Singapure: World Scientific

[9] Nonotna et.al 2014 Problem Solving in School Mathematics Based on Heuristik Strategies *Journal on Efficiency and Responsibility in Education and Science* 7 1

[10] Orton A 1992 *Learning Mathematics: Issues, Theory and Classroom Practice*, Second Edition New York: Library of Congress Cataloging in Publication Data

[11] Sajadi M, Amiripour P, and Maikhalifeh M R 2013 The Examining Mathematics Word Problem Solving Ability under Efficient Representation Aspect *Journal International Mathematics Education Trends and Research*, Available online at www.ispacs.com/met

[12] Samuel G & Andreas F 2013 Measuring complex problem solving an educational application of psychology theories *Journal for Education Research online* 5 38 Um.nbn:de:0111.opus.80196

[13] Tambychik T and Meerah T S M 2010 Students’ Difficulties in Mathematics Problem-Solving: What do they Say? *Prodia Social and Biheviorical Science* 8 142 Available online at www.sciencedirect.com