

## Learner's strategies for heuristic ability in mathematics at the secondary level in Khyber Pakhtunkhwa, Pakistan

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### Abstract:

This study explores the learners' strategies for heuristic ability in mathematics at the secondary level. The study is qualitative, and the method adopted for obtaining information about the learner's strategies is a case study. The site selected is Govt. Girls Higher Secondary School Rustam, Mardan, Khyber Pakhtunkhwa, Pakistan. Participants of the study were six in number, selected from science group students of the 9th class based on their interests. A test of non-routine problems was used for the collection of data. Six non-routine problems were given to the students to check their heuristic ability. Non-routine problems were analysed through cognitive strategies. No scoring of students was considered in this study. The researchers categorized the learner's responses so that students who solved questions by applying complete strategy were marked with the word excellent, the half strategy was marked very good, and unsatisfactory solutions were marked satisfactory. The study investigated learners' strategies such as making tables, using formulas, guessing, making diagrams, doing trial and error, logical reasoning, non-logical reasoning and looking for patterns. Results show that students who are interested, motivated and have a positive attitude toward learning practice various methods for solving non-routine problems.

**Keywords:** learner's strategies, cognitive strategies, heuristic ability, non-routine problems, mathematical problem, problem-solving, problem-solving skills.

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## 1. Introduction

Mathematics is a core subject at the secondary level. Most of the students do not like it and consider it a very difficult subject. Almost in every field of life, it is used even in social sciences it is used for calculating the population's average birth rate and so on (Chen *et al.*, 2106). Even used for determining the success of the implementation, the success of students absorbing learning material and the ability of students is a key factor. Those students who understand the mathematical concept can use the heuristic ability in a better way while those students who depend upon cramming, cannot use this ability effectively. With the help of Heuristics, math facts or math problems can easily be solved (Burns, 2011). The Heuristic can be used as a rule of thumb in solving the problem. Heuristics gives a guideline to the problem solvers for the solution of a problem. Humans automatically developed make simpler shortcuts or rules of thumb in solving intricate problems. Such simplifying shortcuts are called heuristics. Heuristics which are accordingly important for addressing problems of complexity in cognitive information processing and increase in resulting complexity thus increases result in peoples' ending of choices (Tambunan, 2014). In short, it can be said that heuristic is shortcut, self-developed and self-proposed strategy for the solution of a problem.

Schoenfeld (2015) agreed that there are four main groups of individual problem-solving activity such as knowledge, heuristic strategies, belief systems and metacognition. Current studies investigate cognitive strategies and the effects of heuristic ability on the selection of cognitive strategies. This system is trying to study the subject, only moderately rewarding our purpose systematically. Rodrigues (2014) expresses his view about solving mathematical problems and the variables related to them, these variables are the knowledge, belief system of learners and teachers, strategies, cognition, and metacognition experiences. These variables are very important for increasing problem-solving skills. Malouf (2011) noted that even though a heuristic leads a learner to obtain a solution in any given problem situation, but the solution is not guaranteed.

This study determines learners' strategies for heuristic ability at the secondary level. This study is also likely to identify strategies adopted by the learners during solving non-routine problems which further help the teacher in selecting the methods for teaching and knowing of mathematics concepts. It may be a rich contribution to the teachers that are aware of the learner heuristic ability in the subject of mathematics of their students and also teachers will know better about problem-solving ability in the mathematics classroom. The objectives of the study are to investigate Learners' *strategies* for heuristic ability at the secondary level in Khyber Pakhtunkhwa. This study's research question is about what are the 9<sup>th</sup> grade learner's strategies for heuristic ability.

## 2. Literature review

Mathematics is a core subject at the secondary level. Most of the students do not like it and consider it a very difficult subject. Mathematics is used to calculate the population, average birth rate, and so on (Chen *et al.*, 2016). In the 21<sup>st</sup> Century, the problem-solving ability is essential for learning and for this purpose, innovation is an intense need which may be developed later on. Consequently, innovation is needed so that students can have the ability to solve problems. Setiaji (2018) has said that teaching through the discovery model not only creates discovery skill but also improve problem-solving abilities. The discovery learning

model is the activity that involves those activities which enhance searching and finding things. Those things may be objects, people, or events. This enhancing process is systematic, critical, logical and analytical. In this way, they answer with self-reliance. According to Gitatena *et al.* (2020) heuristics is a guideline containing questions needed to solve problems. The heuristics provide direct instruction to the learners to find out the solutions for a given problem.

A heuristic is the most powerful tool for solving problems. The founder of heuristic is the Hungarian Mathematician George Polya who published the book "How to solve it" in (1945). A heuristic is a non-algorithm device used for solving mathematical problems. A Heuristic is a trial to signify an opportunity to set up fresh activities in the classroom. A heuristic is an approach to problem-solving or self-generated strategy that utilizes a realistic method whose results are not guaranteed to be optimal, great, or rational. The aim of heuristic is to arouse students' creativity and critical review about what is being learned, and for what purpose. A Heuristic help to find out the solutions. Heuristics are generally plans that help learners to go towards their solution. Heuristics is a guide that can lead problem solvers to find a solution to the problem. Humans automatically develop simpler shortcuts or rules of thumb in solving intricate problems. Such simplifying shortcuts are known as heuristics. Heuristics which are accordingly important for addressing problem complexity in cognitive information processing, increases as complexity increases resulting in peoples ending choices (Tambunan, 2014).

The heuristics ability is best used with students who understand the mathematical concept but who have trouble remembering the steps in completing a problem. The use of heuristics or self-strategies in mathematics can have a deep contact with a student's ability to quickly and accurately solve a math fact or word problem (Burns, 2011). Hoon *et al.* (2013) studied the title of Heuristic approach experience in solving mathematical problems. The researchers said that the heuristic approach is a mean to sharpen cognitive ability on the basis of which he/she becomes the best problem solver. The learners who possess strong beliefs in applying for the heuristic approach show better experience towards mathematical problems. This study also concluded that through the practice of a heuristic approach, the learners are able to solve different difficult problems in a very easy way.

In addition, the researchers focused on group activity and explained that group activities enhanced heuristic ability and brought confidence in the process of problem-solving. Pimta *et al.* (2009) investigated the factors that affect heuristic ability are direct and indirect factors. Beliefs about mathematics, self-respect, classroom environment, teaching methodology and behaviour are the direct factors which affect problem-solving or heuristic ability while indirect factors are motivation and self-confidence. The researchers concluded that the behaviour of teachers highly affects both direct and indirect effects of problem-solving or heuristic ability. The behaviour of teachers and their attitudes also develop a heuristic ability as well as the positive beliefs of the learners towards mathematics (Malouff, 2011).

A strategy is a routine for accomplishing a goal. There are different cognitive heuristic strategies which are: guess, check and revise simply GCR is a heuristic strategy in which the learner first guesses the answer or the solution to the problems and checks the guess for satisfaction and then evaluates the solution for correctness. Making a systematic list in which the learners organize a list from the given problem and visually consider their options when answering a problem. Third looking for the pattern is another strategy for problem-solving, the solver first looks for the pattern which is to draw a table or make a figure so with the help of a

table and diagram the learner solves the problem. Fourth is eliminating possibilities: The learner mostly solves logical problems of mathematics in this strategy. The student process is eliminating until it reaches the correct solution. The fifth is logical reasoning: A heuristic strategy which involves the learner for the Venn diagram or chart for a logical sequence. A hierarchical chart for solving the problem. The learner read the problem and paraphrased the necessary information. The sixth is to draw a picture: Some learners are not capable of retaining the numbering and other information, so he/she draws a picture. To represent the problem, translate the words into a picture or equation. The steps used for this strategy are known by the word STAR: S: Search the words problem; T: Translate the words into a picture or equation; A: Answer the problem; R: Review the solution.

Seventhly using the formula: The most common use strategy is using the formula. The students memorize or learn the formula and then solve questions based on the formula. The learner combines the like terms and then asks to isolate the variable and put the values in the given formula. This strategy is also known as an algorithm. Working backwards: It is a downfall strategy in which the important parts of the question are used for the solution. Lastly mnemonic devices: The strategy which the teachers create to help students remember content. They are memory support in which specific words are used to remember a concept or a list. Verbal information promotes the recall of unfamiliar information and content. For example, for mathematical operations, PEMDAS is commonly used by students and teachers. To develop students' strategies, they need to work on different types of problems. The Heuristic guides students in the proper ways of finding solutions. The outcome of heuristic strategies does not guarantee but can provide an immediate solution. Elia *et al.* (2009) sorted two types of heuristic strategies one is cognitive, and the other is metacognitive strategy. Cognitive strategies are the general and common strategies used for problem-solving while metacognitive heuristic strategies are specific because it is the thinking about such types of strategies that are related to self-regulation, observing, control and executive decision.

Ang and Lau (2019) argue that the heuristic solution method relies on spontaneous or simple rules, which apply to the problem and offer more than one solution for a single problem. Zeitz (2007) imagines that when learners hold the solution to a mathematics problem, they take some aspects to form manners. For example, the behaviour of problem-solving is knowledge base heuristic strategies, cognitive, a metacognitive strategy, mathematics-related belief systems and skills of solving the problem. Wästlund *et al.* (2015) found that Namibian grade 12 learners were unable to solve non-routine problems due to their comprehension and language problems and also low knowledge about the strategies, so they faced problems in solving tasks. For teaching and learning mathematics problem-solving phase is very crucial (Abdullah *et al.*, 2019; Ullah *et al.*, 2017). Břehovský (2013) describe heuristic ability as a problem-solving skill that possibly makes a shortcut to reach the goal or may lead to the desired solution of the problem. To be able to solve problems effectively, students need to be familiarized with problem-solving/heuristics (Ang & Lau, 2019; Ullah *et al.*, 2018). Current study aims to investigate learners' strategies for non-routine problem-solving.

### **3. Conceptual framework**

The researchers selected the problem based on experience in the teaching of mathematics at the secondary level "learner's strategies for heuristic ability." For this purpose, different publications regarding cognitive strategies with the selected variable "heuristic ability as well

as with other variables” are read. The researchers investigated a variety of strategies for solving the problems. Non-routine problems were selected because non-routine problems are defined as “a cognitively non-trivial task; the solver does not already know a method of solution.” The result's answers to non-routine problems are unknown and not guaranteed. The investigator also checked the effects of heuristic ability on the selection of cognitive strategy.

## **4. Methodology**

### **4.1. Research design**

The method implemented for this study is the qualitative research method. A single case study design for implementing the current study. Participants of the study were six students selected from 9<sup>th</sup> class science group based on their interests. Test of non-routine problems was used for the collection of data. Six non-routine problems were given to the students to check for their heuristic ability as well as their cognitive strategies for solving the problems. Non-routine problems were analyzed through cognitive strategies. The site selected for the study was GGHSS Rustam.

### **4.2. Non-routine problem test**

A non-routine problem is defined as “a cognitively non-trivial task; the solver does not already know a method of solution.” The result of these problems is unknown and not guaranteed. One of the most important tools for this study was a non-routine problem test for checking the heuristic ability of the students. No scoring of students was considered in this study. The researchers categorized the learners' responses in such a way that those students who solved the question by applying full strategy were marked excellent and for half strategy, good were marked very good and for the average researchers used the word satisfactory. The researchers just checked the strategies used by the students. Instruments used during the study were six problems presented to students. Test was pilot tested on seven students who were not part of the sample for validity of the tool. In pilot study, two problems were skipped due to their difficulty level and thus remained six problems. In selection process, only those problems were selected that had more than one solution method and of different strategies. The number of items in the test were based on the previous research done by (Chirove, 2014). Items for the test of non-routines problem were developed by the researchers from different sources. Test was validated by two mathematics teachers and supervisor.

### **4.3. Instrument**

Tools for this study were non-routine problem tests for checking the heuristic ability of the students. No scoring of students was considered in this study. Responses of the learners for the solution of the problem were marked with excellent for using full strategy, very good for half strategy and for unsatisfactory solution of the problem used satisfactory. The strategies used by the students during solving non-routine problems were guess, check and revise (GCR), make an organized list or systematic list, look for pattern, eliminating possibilities, logical reasoning, no logical reasoning, draw a picture or modelling, using the formula or algorithm, working backwards, trial and error, consider the simple case and non-attempts. The researchers formulated a coding scheme for each problem.

Table-1: Coding scheme for the problem-solving strategies.

Strategy name	Abbreviated name of strategy	Details
Organizing listing	OL	The trials move in one direction, note the necessary information
Making diagram	MD	Making diagram, draw picture or sketches, linear equations
Trial-and-Error	T & E	Try to solve question more than one time for the correct solution.
Guess, Check and Revise systematic(sys) or unsystematic (un sys)	GCR both sys & un sys	Guess the answer then check it and revise. Sys: guess, check & revise while in un sys: only guess not check & revise
Using Formula	F	First choose the formula then solve according to this formula
Elimination of possibilities	EP	On the basis of given information incorrect answer are eliminated
Logical reasoning	LR	By using the logical statements reaching to the possible solution, using of sense
No logical reasoning	NLR	Unable to attempt the question, no use of sense
Look for pattern	LP	Classify some general characteristics that can be generalized for solving the problem.
Not Attempted	N/A	Not understand

Source: Adapted from Eliaet *et al.* (2009) and Mabilangan *et al.* (2011)

According to Mabilangan *et al.* (2011), the examiner categorizes heuristic tactics of the pupils into three classes that is full strategies, half-done strategies and incomplete strategies. To make easy analysis of the approaches adopted by the pupils to problem-solving, a degree system was employed for the adopted strategy or strategies that is very good, good and satisfactory. Very good for full use of strategies, good for half-done use of strategies, similarly satisfactory for incomplete strategies, not attempt (NA) not solving questions.

Table-2: Categorization of the strategies for problem-solving

Full strategies	Half-done strategies	Incomplete strategies
The learners proof the answer with evidence of the help of their cognitive thinking	The learner use strategies But not very clear.	There is no clarity and evidence in the strategy use by the solver
The rules followed by the learners are clear	The problem solves adopt the half-done strategy	Not adopted step-by-step procedure
Use of suitable strategies and according to the nature of the problem	The problem solver starts correctly but skip some steps	Strategies are unsystematic T
The learner gives full detail and simplification for the solution of the problem.	The solver knows the process but unable to apply correctly.	The problem solver unable to solve the problem and give he required answer.

Source: Adopted from Mabilangan *et al.* (2011, p. 28)

### 5. Learners' strategies for non-routine problem-solving

The six selected learners solved the problems using the following strategies:

Table-3: Summary of non-routine problems solving strategies applied by the learners.

Learners	Problem 1	Problem 2	Problem 3	Problem 4	Problem 5	Problem 6
R1	GCR unsys	F	T&E+ EP+LR	F+OL	ORL	NA
R2	OL+GCR sys	MD	F	MD	NA	T&E
R3	LR	MD+LR	T&E	GCR sys	LR	NA
R4	GCR unsys	NA	NA	NA	OL	GCR unsys
R5	LP	NA	GCR sys	MD+LR	GCR sys+OL	NA
R6	GCR unsys	MD	NA	NA	NA	MD

Some student's sample work showed in the table-4 give below. Respondent 1 solved problem with different strategies. The learner solved problem 1 with GCR unsys, problem 2 with formula, problem 3, problem 4 with formula and OL, problem 5 with ORL and problem 6 were left not attempted.

Table-4: Strategies for solving problem

Strategy	Q.3. There are rabbits and some rabbit hutches. If seven rabbits are put in each rabbit hutch, one rabbit is left over. If nine rabbits are put in each rabbit hutch, one hutch is left empty. Can you find how many rabbit hutches and how many rabbits are there?	
F + EP + LR	<p>Answer</p> <p>In formula, H is for hutch,</p> $7H+1=9(H-1) \quad \text{eq.(i)}$ $7H+1=9H-9$ $1+9=9H-7H$ $10=2H$	Rough calculation
Very good	<p>Dividing both sides by 2, we get</p> $5=H \text{uches}$ <p>Now putting the value of H in eq.(i)</p> $7(5)+1=9(5-1)$ $35+1=45-9$ $36=36$	<p>So, the number of rabbits is 36. So, from the above equation, we know that hutches=5</p> <p>Rabbits=36</p>

Respondent 2 solutions strategies for non-routine problem are given below.

Table-5: Strategies for solving problem by learner 2

Strategy	Q. 4 On the new year party, there are eight cousins giving greeting cards with one another. How many cards are distributed among them?	
MD Excellent	<p>Answer</p> <p>Cousin-1    Cousin-2 Cousin-3    Cousin-4 Cousin-5    Cousin-6 Cousin-7    Cousin-8</p> <p>Greeting cards distribution among these.</p> <p>7 multiplied by 8=56</p>	<p>Rough calculation</p> <p>Every one in eight cousins distribute seven cards so</p> <p>7 multiply by 8=56</p>

Next is the respondent 3 solutions strategies for non-routine problem. The learner solves problem 1 with trial and error, problem 2 with making diagram and logical reasoning as shown in the Table 6. She solves problem 3 with trial and error, problem 4 with GCR sys problem 5 with LR and left problem 6 unsolved.

Table-6: Solution procedure for learner 3

Strategy	Q.2. In a primary school there are five teachers along with their head teacher. Every morning all of them shake their hands. How much hand shaking among them every morning?	
5 hands shaking LR Excellent	<p>Answer</p> <p>Teacher-1    Teacher-2    Teacher-3    Teacher-4                   Teacher-5    Teacher-6</p> <p>Handshaking among these.</p> <p>5+4+3+2+1=15 Handshaking</p>	<p>Rough calculation</p> <p>Teacher-1    Teacher-2 Teacher-3    Teacher-4 Teacher-5    Teacher-6</p> <p>Last teacher already hand shaken with other five teachers</p>

Respondent 4 solve non-routine problem 1 with the with GCR (usnsys), problem 5 with organizing list a problem 6 with GCR unsys she unsolved problem 2,3,4.

Table-7: Solution procedure for learner 4

Strategy	Muhammad Inshal has kept 18 animals in his home. Some are kept. There are 50 legs in all. How many hens and cows are there?	
GCR Un systematic Satisfactory	<p>Answer</p> <p>Total animals=18 Cows=07 Hens=11</p>	<p>Rough calculation</p> <p>50 – 28=22 answer.</p>

The learner solves problem 1 with LP, problem 3 with GCR unsys, problem 4 with MD+LR and problems with GCR (sys).

Table-8: Solution procedure for learner 5

Strategy	Q.5. There are three subjects in examination. Find out the number of ways of fail in the subjects in this examination?	
GCR(ONLY) Satisfactory	<p>Solution:</p> <p>Number of ways are:</p> <ol style="list-style-type: none"> <li>1. Urdu, Maths, English, English, Urdu,</li> <li>2. Urdu, Maths,</li> <li>3. Maths, English,</li> <li>4. English, Urdu,</li> <li>5. Maths</li> <li>6. Urdu</li> <li>7. English</li> </ol> <p>Fail possibilities=07</p>	<p><u>Rough calculation</u></p> <p>For example, the subject in examination: Possibilities in three subjects at a time English, Urdu, Maths. Possibility three in one Possibility in two subjects. Number of ways of fail in the subjects.</p>

Respondent 6 solved problem 1 with GCR unsystematic, problem 2 and 6 with making diagram (MD) while left unsolved problem 3, 4 and 5.

Table-9: Solution procedure for learner 6

Strategy	Q.6. A man climbs on twenty-five meter tall pole. In one second, he climb three meters but unfortunately he slips by two meters. How much time he will take to top of the pole?	
MD+GCR(ONLY) Satisfactory	<p>Answer</p> <p>Twenty-five-meter-tall pole total time he will take to top of the pole is 25 seconds.</p>	N

## 6. Discussion

This investigation recognizes learners’ strategies during solving non-routine problems. The result exposed that some of the learners put into practice multiple heuristic strategies during problem-solving. The selection of strategy for solving problems was depending on the interest, motivation, attitude, and heuristic ability of the learners. Those students who were highly motivated towards learning mathematics used varieties of cognitive strategies i.e., logical reasoning, using the formula, making tables, making diagrams, trial and error, guess, check and revise (GCR), looking for patterns and elimination of possibilities. The result of the study showed that the use of strategies and approaches for solving a problem in mathematics highly depends on the heuristic ability of the learners. During the investigation, the researchers also noticed that heuristic ability not only affects the selection of cognitive strategies but is also affected by other factors such as learners’ beliefs, teacher methodology, classroom environment as well as their home environment.

Based on the research question, the following findings were made. The learner use several of cognitive strategies i.e., logical reasoning, using the formula, making a table, making of diagrams, trial and error, guess, check and revise (GCR), looking for patterns and elimination

of possibilities. During the investigation of the study other factors were observed such as learner's beliefs, teacher methodology and classroom environment. Seventy-five percent of learners used various and proper strategies for solving non-routine problems who have the good heuristic ability, on the other hand those students who had low heuristic ability were shown unsatisfactory performance for solving non-routine problems.

## **7. Conclusions**

This study intended to investigate learners' strategies for non-routine problem-solving. The researchers concluded from the result of the non-routine problem-solving task that the learners who have passionate heuristic ability used multiple methods for a single problem. For example, they used logical reasoning, guesses, checking and revising systematically, use of diagrams and sometimes making a table for the clearance of the concept or solution. In some problems, one learner used more than one solution for a single problem. This study concluded that the use of strategies and approaches for solving a problem in mathematics highly depends on the heuristic ability of the learners. Learners who have low problem-solving abilities face difficulties in dealing with non-routine problems. During the inquiry, the investigator also noticed that heuristic ability not only affects the selection of cognitive strategies but is also affected by other factors such as learners' beliefs, teacher methodology, classroom environment as well as their home environment.

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