INVESTIGATING THE COGNITIVE PROCESSES IN SOLVING MANAGEMENT SCIENCE PROBLEMS

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ABSTRACT

Despite the fact that Operations Research (OR) or Management Science (MS) has broad applicability, from health care to logistics to financial services, career opportunities and work styles, there is a lack of research done in cognitive processes with regard to problem solving in this area. This study investigated the cognitive processes used by Malaysian undergraduate business degree students (MUB students) in solving the ill-structured and well-structured MS/OR problems. Further investigation was conducted to probe the roles of problem solving in well-structured and ill-structured problems on individual decision making. In-depth observations and interviews were conducted on six willing participants. Results of the study reveal that the performance of well-structured problems was independent from the ill-structured problems. However, there were differences in the cognitive processes of solving well-structured and ill-structured problems. Results of the study also found that approaches to solving well-structured and ill-structured problems influenced the individual's decision making outcomes. Arising from these findings, an algorithm has been proposed in an attempt to improve the cognitive processes of students in solving MS/OR problems as well as the quality of decision making. The findings have implications for the development of effective MS/OR related subjects.

Keywords : Problem solving, cognitive processes, decision making, Management Science, Operations Research

1.0 INTRODUCTION

Cognitive process in problem solving is one of the fundamental human cognitive processes [1], which is referring to human thinking and information processing [2,3]. Problem solving is a nearly ubiquitous human activity. The domain of the problems ranging from highly structured to ill-structured in real life [3]. Learning problem solving strategies is not only helping the learner to acquire a store of knowledge but also cognitive skills that are useful in broad situation that might be encountered in a world of globalization[4]. Ormrod (2008) defined cognitive process as a particular way of mentally responding to or thinking about information or an event, while problem solving is referred to using existing knowledge and skills to address an unanswered question or troubling situation [5]. By way of definition from Ormrod (2008), cognitive processes in problem solving can be operationalised as the thinking processes and recalling of existing knowledge and skills to resolve a problem. From the perspective of Management Science (MS) /Operations Research (OR), Rosenhead (2001) has aptly defined problem solving as the cognitive processes of identifying differences between the actual and the desired state of affairs and then taking action to resolve the difference [6].

Operations Research (OR) Professionals are always engaged problem solving with the aim to provide rational bases for decision making by seeking to understand and structure complex situations, use this understanding to predict system behavior and improve system performance [7]. Much of this work is done using analytical and numerical techniques to develop and manipulate mathematical and computer models of organizational systems composed of people, machines, and procedures[8]. MS/OR is characterized by its broad applicability, from health care to logistics to financial services; and by a wide variety of career opportunities and work styles it embraces. OR has much to offer in making a difference in the real world by helping people to make better decisions [9]. However, despite the wide spread applicability, there was a dearth of research in investigating the cognitive processes in

problem solving in the area of Operations Research (OR) or Management Science (MS). Yet, several studies on cognitive processes particularly in science and mathematics [1,4] found there exist certain relationships between cognition processes and problem solving. These studies reveal that if these relationships are fully understood, then they would be able to enhance the pedagogy of facilitating student's ability to solve OR/MS problems in a more systematic and accurate way.

This paper is part of a wider research programme in investigating the cognitive processes of solving MS/OR problems. The main research question was to ascertain the cognitive processes demonstrated by students in solving well-structured MS/OR problems and ill-structured MS/OR problems. The well-structured problems are characterised by well-defined and give clear goals for problem solvers to assess them in a logical manner, while the ill-structured problems are those without any particular hint on the patterns of approach and generate more than one solution [10].

There is a scarcity of research on the cognitive processes used by students in solving MS/OR problems [7], and hopefully the findings of this research could provide further insights in the understanding of the algorithms students used of solving both well- and ill-structured problems. As problem solving is related to decision making, the study has also attempted to propose a framework for decision making.

2.0 RESEARCH METHODOLOGY

A qualitative research design was employed via observations and semi-structured face-to-face interviews. Observations and interviews were chosen for the research as these techniques ensure that the researcher could obtain in-depth and comprehensive information, while at the same time participants have freedom to respond and illustrate the cognitive processes involved in problem solving.

2.1 Design

This study is intended to investigate the cognitive processes in problem solving of Malaysian undergraduate business (MUB) students while they solve the well- and ill-structured MS/OR problems. The data collection involved the observations of six participants performing the tasks individually and these processes were video-taped. Interviews were immediately conducted based on the 'solved' problems and were audio recorded. MUB students were encouraged to use the "thinking-aloud" approach during the problem solving session.

2.2 Participants of the Study

A purposive sample comprising six willing participants were selected from the BSc degree programme in Accounting and Finance cohort. The selection was based on their prior knowledge in Management Science/Operations Research, which happened to be one of their subjects in the degree programme, as well as their exposure to the well-structured and ill-structured MS/OR problems and decision making models.

2.3 Instruments

In investigating the cognitive processes of solving MS/OR problems, two types of problems have been posed to the MUB students to solve namely, well-structured and ill-structured problems. Well-structured problems are those problems with clear goal, firm constraints and established cause-effect relationship, and generate only one correct solution [11,12 &13]. In solving a well-structured MS/OR problems, a student has to access his/her learnt knowledge in Linear Programming (LP) to obtain numeric solution – a 'best possible' answer. Ill-structured problems, on the other hand are referred to problems that are not provided with any particular hint on the pattern of approach, with unclear desired goal and more than one possible solution exist [11,12 &13].

The well-structured was adopted and adapted based on the course text, Beasley (2004) Students' Study Guide, as indicated below:

"A company is involved in the production of two items (X and Y). The resources needed to produce X and Y are twofold: namely, machine time for automatic processing and craftsman time for hand finishing. The table below gives the number of minutes required for each item:

		Machine time	Craftsman time
Item	X	13	20
	Y	19	29

The company has 40 hours of machine time available in the next working week but only 35 hours of craftsman time. Machine time is costed at RM10 per hours worked and craftsman time is costed at RM2 per hour worked. Both machine and craftsman idle times incur no costs. The revenue received for each item produced (all production is sold) is RM20 for X and RM30 for Y. The company has specific contract to produce 10 items of X per week for a particular customer.

Formulate the problem of deciding how much to produce per week as a linear program. Solve this linear program graphically."

In terms of ill-structured problem, the question was constructed based on the guidelines of problem structuring methods (or Soft OR) developed by Rosenhead (2001), which emphases the importance of each individual's perception of the situation [6].

"A CEO of a manufacturing company is NOT happy with the current production output. If you were the production manager, what will you do?"

In particular, this question gave students the free hand to solve the problem, but no hint or guidelines were given. As a result, there was no fixed solution, which was in line of the nature of ill-structured problems.

Both the well- and ill-structured problems were subjected to content validation by three experts who have been involved in teaching or practicing problem solving in OR/MS.

2.4 Data Gathering Procedures

The data collection was conducted individually in an air-conditioned classroom setting where table, chair and stationery were provided. The behaviours and cognitive processes of solving the two types of problems were video recorded, and upon completion, each participant was interviewed. A video camera was set up to record the entire problem solving session and an interview was also audio-recorded. Both recordings were transcribed, analysed and coded, also validated by the three experts.

3.0 RESULTS AND DISCUSSIONS

This main purpose of the study was to investigate the cognitive processes used by MUB students in solving the ill-structured and well-structured MS/OR problems. Six MUB willing participants from the University of London International BSc degree programme in Accounting and Finance participated in the study.

3.1 Cognitive Processes Involved in Solving MS/OR Problems

The cognitive processes of participants were determined through observations and interviews in solving well- and ill-structured problems in MS/OR.

3.1.1 Cognitive Processes Involved in Solving MS/OR Well-Structured Problem

In terms of the well-structured problem, it was found that although all students knew that it was a linear programming problem, however at the initial stage, most of them were unsure whether maximization of profit was the objective of this problem. This was due to the fact additional information (used as distracters), in this context, the figures of cost and revenue were provided in the question. Nevertheless, four of the students managed to determine the objective function and were able to formulate the mathematical model correctly, while the remaining two students could not clearly write out the "maximization" or "minimization" of objective function. Instead, they just wrote "objective function or profit". Table 2 provides a detailed account of the behaviours of and strategies used by successful and unsuccessful participants in solving well-structured MS/OR problem.

Table 2: Behaviours of Participants and Strategies Used in Solving Well-Structured MS/OR Problem

Student's Name	Successful / unsuccessful Solver	Observed behaviours and interview of students to solving well-structured problem	Strategy
YZ	Successful	• Read the question, confused look	• Reading the problem
		• Repeated reading the question, got the idea.	• Reading and analyzing
		• Formulate the mathematical model by following the algorithm of solving the LP problems. Write out objective function, structural constraints, and non-negativity.	• Planning and exploring and implementing
		• Solve the problem by graphical approach: solve each inequality to obtain x and y coordinates; draw x-axis and y-axis with appropriate intervals. Plot points and form lines to form a feasible area, finally, an optimal point was found.	• Analysing and implementing
		• Refer to the mathematical model and look at the answer	• Verifying
MG	Successful	• Reading the question	• Reading
		• Abstract information from the question	• Analysing and planning
		• Wrote down the mathematical model: a) Objective function, b) structural constraints, and c) non-negativity.	• Exploring and Implementing
		• Solve the problem by graphical approach: solve each inequality to obtain x and y coordinates; draw x-axis and y-axis with appropriate intervals. Plot points and form lines to form a feasible area, finally, an optimal point was found.	• Analysing and implementing
		• Refer to mathematical model and check on the objective function.	• Verifying
NE	Unsuccessful (with minor mistake in final answer)	• Read the question, on the question paper, underlined "machine time" and "craftsman time"; circle "40 hours" and "35" hours; wrote down costs "RM10" and "RM2" for machine time and craftsman time respectively.	• Reading and analyzing
		• Wrote down information on the answer paper.	• Analyzing and planning

		• Started formulate the mathematical model, step by step and clearly numbered each inequality.	• Implementing and exploring
		• solve each inequality to obtain x and y coordinates	• Analysing and implementing
CY	Unsuccessful (with mistake in objective function)	• Read the question, on the question paper, underlined “per hour worked”, circle costs “RM10” and “RM2”; drafting objective function and one constraint.	• Reading and analyzing the problem
		• Started formulate the mathematical model, step by step and clearly numbered each inequality.	• Implementing and exploring
		• Attempted to take into the consideration of costs in the objective function.	• Analysing and exploring
		• Solve each inequality to obtain x and y coordinates	• Implementing
		• Draw x-axis and y-axis with appropriate intervals. Plot points and form lines to form a feasible area, finally, an optimal point was found.	• Analysing and implementing
		• Refer to mathematical model	• Verifying
SC	Unsuccessful (with mistake in objective function and one constraint missing)	• Reading the question and abstract information from the question, directly formulate the mathematical model.	• Reading and analysing
		• Wrote down objective function and 2 constraints.	• Implementing
		• Solve each inequality to obtain x and y coordinates	• Implementing
		• Draw x-axis and y-axis with appropriate intervals. Plot points and form lines to find an optimal point. Also indicated one constraint was “relundant constraint” (- means “redundant”)	• Planning and implementing
		• Refer to the question. Suddenly realized something missing. Re-read the question again and re-started all over.	• Verifying
		• The question was solved with one answer x.	• Implementing
WS	Unsuccessful (not able to recall the algorithm of solving LP problem)	• Reading the question	• Reading & analysing
		• Abstract and wrote down information on the answer paper.	• Planning and implementing
		• Used his own way to analyse the question and worked out the equations according to his understanding.	• Implementing and exploring
		• Leave the equations with unknowns, he declared task completed.	

3.2.2 Cognitive Processes Involved in Solving MS/OR Ill-Structured Problem

Although all students had been exposed and taught the soft OR, i.e. how to formulate complex problems, majority of them were not able to recall how to do it. It was found that during the interviews, they did not like this topic and did not pay much attention to it. Nevertheless, three of them used cognitive map ('part of the JOURNEY MAKING process' in soft OR) to approach the problem. The remaining three participants used their own way to analyse and approach the problem. The behaviour of participants and the strategies used in solving ill-structured are summarised in Table 3.

Table 3: Behaviours of Participants and Strategies Used in Solving Ill-Structured MS/OR Problem

Student's Name	Observed behaviours to solving ill-structured problem	Strategy
YZ	• Read the question carefully.	• Reading & analysing
	• Use cognitive map approach	• Planning and implementing
	• Constantly refer to the question	• Understanding and verifying
	• Write out "increase production output" (make assumption), list down the possible factors contribute to the goal.	• Exploring and planning
	• Draw boxes to indicate the relationship	• Implementing
	• Found out which factor was the cause and tackled the problem.	• Implementing
MG	• Read the question carefully.	• Reading and analysing
	Llist down 2 possible factors and elaborate further factors from them.	• Planning and exploring
	• Draw oval shape to indicate the relationship	• Implementing
NE	• Read the question slowly and carefully	• Reading and analysing
	• Write out "CEO is happy with the production output" (make assumption) by increasing production output to a satisfied level.	• Planning and exploring
	• Cognitive map is constructed to reflect the individual's opinion	• Implementing
CY	• Read out the question, practise "thinking-aloud" method	• Understanding
	• Write out 3 boxes below "CEO NOT happy with the production output". (make 3 assumptions on the possible causes).	• Planning and exploring
	• Based on each assumption, process and action were proposed to take accordingly.	• Implementing
	• Boxes were drawn to indicate the relationship.	• Implementing
SC	• Read the question very fast.	• Reading
	• List out what he interpreted on "CEO NOT happy…" and assumed that profit maximization output would make the CEO happy.	• Planning and exploring
	• List out 3 constraints (factors) which might contribute to the situation	• Implementing
WS	• Read the question	• Reading
	• List down the key point from the question	• Planning
	• Work on the conventional notes, point by point	• Implementing

Participant CY was the only one that used the “thinking-aloud” approach. However, at the beginning, he read the question aloud, but his voice became progressively softer and finally he just mumbled. Others preferred to think silently while solving the problem, even though the researcher kept encouraging them to express themselves ‘loudly’.

The results indicate that the cognitive processes in solving well- and ill-structured MS/OR problems were to some extent similar. For an example, when participants attempted to solve both the well-structured and ill-structured MS/OR problems, they had to first read and analyse the objective of the problems, followed by recalling their knowledge in planning stage. However, the time spent in solving a well-structured MS/OR problem and ill-structured MS/OR problem was somehow different. In this study, the results show that participants spent more time on solving a well-structured problem than ill-structured problem. This indicates that in their cognitive processes participants were trying to fit into certain patterns and attempted to figure out a “correct” answer. In the case of participant SC, the strategies he used in solving the LP problem was firstly, to work out the solution, but when it came to the “verifying” stage, he realised that he had missed some important information. He then had to start over the problem solving process again in order to ascertain the correct solution, although he did not really know what the exact answer should be. However, he did realise that if he missed some information, his answer would definitely be incorrect.

Unlike the well-structured problem, when participants attempted the ill-structured MS/OR problem, although the problem nature did not provide a clear objective, participants spent less time in figuring out the problem. This indicates that when participants knew that there was no exact “correct” answer, they felt freer to make any assumptions they thought was logical and correct. They did not even bother to the problem and verify the information given. Instead, they just work on their assumptions and implemented them according to their thought. This indicates that prior knowledge and personal exposure could probably be the influential factors. However, the personal preference would be the determination factor when it came to ill-structured problems. In this study, participants YZ, MG, NE, and CY were trying to use their prior learning knowledge in cognitive map to work out the ill-structured problem. However, participants SC and WS, although they have learnt the cognitive map in their soft OR session, they did not like this topic. Hence, they had not paid much attention to understand this topic. Instead, they preferred to use their own way to solve the problem and they felt that it was the right strategy to do.

In sum, it could be extricated from the findings that there are seven steps, participants used in solving the well-structured MS/OR problem and ill-structured MS/OR problems namely:

(1) Understanding the problem
(2) Identifying the alternatives
(3) Exploring the criteria
(4) Suggesting alternatives
(5) Selecting the best alternative
(6) Implementing the Decision
(7) Evaluating the Results

The steps seem to be in tandem with that of Anderson’s (2008) in that he also found similar seven steps[14]. In this study, it is interesting to note that when participants attempted to solve the well-structured problem, their cognitive processes seemed to suggest that they have had a pre-set thought that there would be a convergent/”correct” answer and conformed to this notion. If they could not reach the right answer, they would suspect and wonder whether they had made mistakes. Subsequently, they would perpetually refer to the questions and information provided, until they reached to a certain form of solution, with which they believed to be the “correct” answer. On the other hand, when participants knew that the objective of the problem was ambiguous, they were not conformed to certain patterns. Instead, they had a free hand to use their own preferred method(s) to solve the problem and made the decision accordingly. In this way, they were able to make quicker decision, as indicated in their working time in solving the problems as illustrated in the next section.

3.3.3 Duration in Solving Problems

It would be interesting to trace the time taken participants used in problem solving and time was charted from the video recording. As shown in Tables 4 and 5, for the problem solving for well-structured problem, the time taken by participants in the video recording were between 21 and 42 minutes, while the range of interview time was between 4 and 15 minutes. However, for the ill-structured MS problem, the video recorded that participants took from 4 to 23 minutes, and 5 to 2 minutes for interviews. The entire session per student ranged from 45 minutes to 1.5 hours. Table 4 indicates the time taken participants took in solving well- and ill-structured MS/OR problems.

Table 4: Duration of Working Time and Interviews Participants Took in Problem Solving

	Name	Working Time (min)	Interview time (min)		Name	Working Time (min)	Interview time (min)
Well-structured problem	YZ	39	4.12	Ill-structured problem	YZ	3.24	5.49
	MG	25	5.40		MG	15	5.49
	NE	37	5.55		NE	20.29	9.07
	CY	42	6.07		CY	22.23	9.05
	SC	31	14.26		SC	4.31	11.32
	WS	21	9.17		WS	7.14	10.24

Table 5: Time Taken to Complete the Well-structured and Ill-structured MS/OR Problems

		Working Time (min)	Interview time (min)			Working Time (min)	Interview time (min)
Well-structured problem	Average	32.5	7.43	Ill-structured problem	Average	12.04	8.44
	Std Dev	8.29	3.75		Std Dev	8.27	2.44
	Median	34	5.81		Median	11.07	9.06
	Min	21	4.12		Min	3.24	5.49
	Max	42	14.26		Max	22.23	11.32

It is interesting to note that there is a difference in the time taken in solving well-structured and ill-structured MS/OR problems. For the well-structured problem, the median time was 34 minutes and the mean was 32.5 minutes, while for the ill-structured problem, the median time was 11.07 minutes, with a mean of 12.04 minutes. The difference may be attributed to the nature of the problems and students' knowledge. In terms of standard deviation, both of the well-structured and ill-structured problems solving time were rather similar. However, the range of working time for well-structured problem (21 – 42 minutes) was comparatively narrower than that of the ill-structured problem (3.24 – 22.23 minutes). On the other hand, the interview time for ill-structured problem (average = 8.44, median = 9.06) was relatively longer than the interview time of well-structured problem (average = 7.43, median = 5.81). This study therefore indicates that the time taken to solve well-structured problem was longer than the time taken to solve the ill-structured problem. This finding seems to concur with Anderson (2008) in that it may be attributed to individual's decision making process which is based on the individual's judgment and experience[14].

4. CONCLUSIONS AND IMPLICATIONS

From this study, it was found that there were more similarities than differences in the MUB's cognitive processes while solving well-structured and ill-structured problems MS/OR problems. Similar patterns were found in the cognitive processes in terms of reading and understanding, and identifying the problem. However, in terms of planning, exploring and implementing strategies, the findings seem to indicate that there were notable differences in these stages. For well-structured problems, students' cognitive processes were being restricted to LP's rules and principles, and participants tried to solve with one convergent answer. For ill-structured problem, participants used more flexible cognitive

processes, based on individual preference, judgement and experiences, and they solved the problem according to their own preferred ways.

This study has investigated the relationships of cognitive processes on the outcome of decision making. The results show that the cognitive processes in solving the well-structured and ill-structured problems may affect the decision making outcomes. For well-structured problem, the decision making outcomes tended to be framed into certain patterns or norms, while for the ill-structured problem, the decision making outcomes tended to be more flexible and various, and depended on the individual's experiences and judgement.

Although the findings of this study are limited to a small sample size and might not be generalisable enough to a wider context, the findings however, may be able to contribute to the further understanding of cognitive processes in problem solving particularly related to MS/OR problems. Although this study has found seven steps students used in solving both well- and ill-structured (also concur with Anderson(2008)), one of the steps namely, 'identify the alternatives' may not be applicable to making decisions in MS/OR as it was not observable and measurable. Hence, taking cognizance of the findings of the study as well as other researchers[9,15], only six steps have been proposed as generic algorithmic steps for effective decisions making on MS/OR issues, and are displayed in Figure 1 and table 6.

Fig 1: Proposed Framework for Effective Decision Making in MS/OR problems

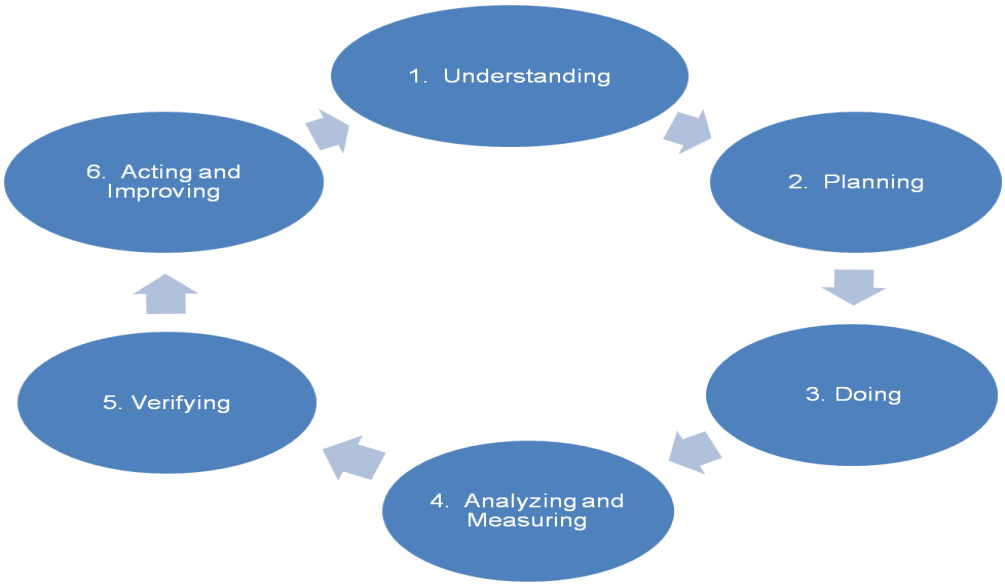

Table 6 : Description of Steps for the Proposed Framework

Steps	Description
1. **Understanding**	- Understand the problem by quick reading of the whole question once, highlight any keywords or figures as you read the question. After that re-read the question again carefully
2. **Planning**	- Planning what to do and recall relevant prior knowledge
3. Doing	- Extract (or write down) the relevant information; sketch or draw out the relationship
4. Analyzing & Measuring	- Identify necessary criteria
5. Verifying	- Refer back to the information given in the problem and do checking
6. Acting & Improving	- Implementing decision, review and refine the outcome

As a concluding note, since this proposed framework is only an initial suggestion, it could be further subjected to further validation and improvements, especially involving a much larger sample size and more robust research methodologies. Hopefully, such research findings could further strengthen the understanding on the cognitive processes students used in solving MS/OR problems as well as to ascertain common generic steps for problem solving and decision making.

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