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Effecting Change on Students' Critical Thinking in Problem Solving

ABSTRACT: *Critical thinking is the intellectually disciplined process of actively and skillsfully conceptualizing, applying, analyzing, synthesizing, and/or evaluating information gathered from, or generated by, observation, experience, reflection, reasoning, or communication, as a guide to belief and action. Most formal definitions of critical thinking characterize critical thinking as the intentional application of rational, higher order thinking skills, such as analysis, synthesis, problem recognition and problem solving, inference, and evaluation. Critical thinking and problem solving have long been important terminologies in the context of education, but within the framework of the 21st century classroom, they take on very specific definitions. Critical thinking employs higher level analytical skills to understand a problem and to work toward a means by which it can be solved, that word implies an answer. This study investigated the effect of using problem situations on the critical thinking of graduate students in solving problems. The study utilized the experimental design participated by a group of graduate students enrolled in Educational Statistics. Four problem situations were utilized that aimed to develop critical thinking of students in problem solving. Students' critical thinking was measured before and after giving th em the problem situations. Results revealed that students' critical thinking in problem solving significantly improved after using problem situations. The students also expressed positive attitude and sentiments towards the used of these problem situations. It is recommended that these problems situations be used in other topics and areas in mathematics.*
KEY WORDS*: Problem Situation; Critical Thinking; Problem Solving; Graduate Students; Positive Attitude and Sentiments.*

INTRODUCTION

There are various definitions of critical thinking in the literature. According to M. Scriven & R. Paul (1996), critical thinking is the intellectually disciplined process of actively and skillsfully conceptualizing, applying, analyzing, synthesizing, and/or evaluating information gathered from, or generated by, observation, experience, reflection, reasoning, or communication, as a guide to belief and action (Scriven & Paul, 1996). Most formal definitions of critical thinking characterize critical thinking as the intentional application of rational, higher order thinking skills, such as analysis, synthesis, problem recognition and problem solving, inference, and evaluation (Angelo, 1995; ten Dam & Volman, 2004; and Lai, 2011).

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C. Wade (1995) identifies eight characteristics of critical thinking. Critical thinking involves: asking questions; defining a problem; examining evidence; analyzing assumptions and biases; avoiding emotional reasoning; avoiding oversimplification; considering other interpretations; and tolerating ambiguity (Wade, 1995). Dealing with ambiguity is also an aspect identified by S.M. Strohm & R.A. Baukus (1995) as an essential part of critical thinking. According to them, ambiguity and doubt serve a critical-thinking function and are a necessary and even a productive part of the process (*cf* Strohm & Baukus, 1995; Malmir & Shoorcheh, 2012; and Laqaei & Mall-Amiri, 2015).

Another characteristic of critical thinking identified by many sources is metacognition. Metacognition is thinking about one's own thinking. More specifically, metacognition is being aware of one's thinking as one performs specific tasks and, then, using this awareness to control what one is doing (Jones & Ratcliff, 1993; and Jaleel & Premachandran, 2016).

Critical thinking and problem solving have long been important terminologies in the context of education, but within the framework of the 21st century classroom, they take on very specific definitions. Critical thinking employs higher level analytical skills to understand a problem and to work toward a means by which it can be solved, that word implies an answer (Resnick, 1987; Cederblom & Paulsen, 2006; and Moore & Parker, 2012).

Often the problems of the present classroom can have as many answers as there are students trying to solve them. Problem solving describes a situation in which students are faced with an authentic and relevant task on which they work toward a solution or more likely an end product (Khandani, 2005). Frequently, if not always, the scenario in the classroom is structured, so that problem solving involves collaboration within a group of students to create an end result, which solves the problem at hand.

In the present mathematics class, students are encouraged to move away from trying to manipulate numbers and formulas to arrive at an answer and instead focus on the metacognitive skills necessary for approaching a problem. Group work can be helpful, since students have the opportunity to work through a problem together and discuss difficulties. The Professor does not tell students how to solve the problem, but asks questions that help the students approach and solve the problem on their own. This doesn't mean that the instructor waits until the students have the answer. Instead, the instructor interacts with the groups, asking questions when a group is stuck or the approach is not clear (Winter *et al*., 2001).

While this teaching method might seem time consuming, students gain a deeper understanding of the work, they are doing than if they simply copied examples that instructor put on the board. Students are learning the process of thinking through problems as an expert would approach a problem and practicing higher-order thinking skills (Resnick, 1987; and Swartz & McGuinness, 2014).

When teaching mathematics, critical thinking skills can be used, practiced, and enhanced by effective cognitive methods. Critical thinking can enhance creative problem solving options by encouraging students to seek new strategies when solving mathematical problems. Mathematics teachers know the importance of mathematical reasoning, for it builds the skills required for higher-level mathematics (Ball, 2003; and Sullivan, 2011).

T. Van Gelder (2005) believes that improving critical thinking abilities requires practice and to be actively engaged in the skill of thinking critically. T. Van Gelder (2001)'s recommendations for improving critical thinking also included practice of: active engagement; transfer of learning; understanding theories; thinking map skills; the ability to identify biases; and being open to what should be considered truth (Gelder, 2001 and 2005).

The results of various studies support the fact that, with practice, students can improve their critical thinking skill levels in this area (Pascarella & Terenzini, 1991; and Lai, 2011). The work of B.R. Reichenbach (2001) and other studies indicate that students can expand their thinking skills, including

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their clarity, accuracy, precision, relevance, depth, breadth, and logic that stills identified in the Universal Intellectual Standards (Reichenbach, 2001; Shahsavar & Hoon, 2013; and Tew, 2015).

In the field of mathematics education, it is generally agreed that critical thinking is very important, especially in problem solving. Students should be able to develop this skill in order to be successful in this age of globalization. Most researches on critical thinking in mathematics education focused on elementary, secondary, and college students, but very few has delved on graduate students (*cf* Fung, Townsend & Parr, 2004; Pellegrino, 2007; and Stinson, Bidwell & Powell, 2012).

This study attempted to test and describe pedagogical practices or strategies on how to enhance critical thinking of graduate students in solving problems in mathematics. Carefully developed problems situations were used to find out if these will enhance critical thinking of students in solving problems in mathematics.

Efforts to develop the critical thinking skills of mathematics have become the main agenda in the curriculum of mathematics education worldwide (NCTM, 2000; Innabi & Sheikh, 2006; and Mason, Burton & Stacey, 2010). Many researchers have also shown that the development of critical thinking skills can improve mathematics achievement (Silver & Kenney, 1995; NCTM, 2000; Semerci, 2005; Jacob, 2012; and Chukwuyenum, 2013).

In fact, critical thinking skills will encourage students to think independently and solve problems in school or in the context of everyday life (CCT, 1996c; NCTM, 2000; and Jacob, 2012). Critical thinking skills are very important in mathematics learning, because these skills can improve the quality of mathematics learning in better and meaningful way (Cobb *et al.*, 1992). Therefore, students should not only understand the content of mathematics, but also the process of mathematical thinking (Cobb *et al.*, 1992; and Rajendran, 2010).

One of the priorities of the university is to produce graduates who will contribute to the development and improvement of the nation; and critical thinking is very important in developing successful students in this endeavour (Firdaus *et al.*, 2015). Hence, this study is very significant to the research priorities of the university.

Promoting critical thinking and problem solving in mathematics education is crucial in the development of successful students. Critical thinking and problem solving go hand in hand. In order to learn mathematics through problem solving, the students must also learn how to think critically (Semerci, 2005; Jacob, 2012; and Chukwuyenum, 2013).

There are five values of teaching through problem solving. These are: (1) problem solving focuses the student's attention on ideas and sense making rather than memorization of facts; (2) problem solving develops the students belief that they are capable of doing mathematics and that mathematics makes sense; (3) it provides on going assessment data that can be used to make instructional decisions; (4) help students succeed and inform parents; and (5) teaching through problem solving is fun and when learning is fun, students have a better chance of remembering it later (*cf* Marcut, 2005; and Firdaus *et al.*, 2015).

The primary objective is to help the student to become aware of the fact that problem solving is not a special area, but instead uses the same logical processes to which they are already familiar and use routinely (Marcut, 2005). The problem statement itself is the primary cause of novice students' difficulty in solving word problems. The solution is to ignore, when reading a problem statement, any phrases that start with words like "if".

The initial action in starting a solution is identifying what is asked for. The student must be learned to verbalize. A verbal statement following the final result is of particular importance: what does the result tell me? In addition to completing the solution, the ending statement serves as a quick check of one work. An adequate solution presentation does not have to be explained.

Mathematics is often held up as the model of a discipline based on rational thought, clear, concise language, and attention to the assumption and decision-making techniques

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that are used to draw conclusions (Makina, 2010). In 1938, Harold Fawcett (1995) introduced the idea that students could learn mathematics through experiences of critical thinking. His goals included the following ways that students could demonstrate that they were, in fact, thinking critically, as they participated in the experiences of the classroom: selecting the significant words and phrases in any statement that is important, and asking that they be carefully defined; requiring evidence to support conclusions they are pressed to accept; analyzing that evidence and distinguishing fact from assumption; recognizing stated and unstated assumptions essential to the conclusion; evaluating these assumptions, accepting some and rejecting others; evaluating the argument, accepting or rejecting the conclusion; and constantly re-examining the assumptions that are behind their beliefs and actions (*cf* Fawcett, 1995; Robertson & Rane-Szostak, 1996; and Makina, 2010).

Fifty years later, the critical thinking is still present in the goals, but it has been subsumed by more holistic notions of what it means to teach, do, and understand mathematics (Marcut, 2005). In this context, the students will be able to: organize and consolidate their mathematical thinking through communication; communicate their mathematical thinking coherently and clearly to peers, teachers, and others; analyze and evaluate the mathematical thinking and strategies of others; and use the language of mathematics to express mathematical ideas precisely (Marcut, 2005; and Lee, 2015).

These ideas are very similar to those promoted by Harold Fawcett (1995) in 1938. Little has changed in the mainstream ways that people tend to define critical thinking in the context of mathematics education. Students are expected to search for the strengths and weaknesses of each and every strategy offered. It is no longer good enough to reach an answer to a problem that was posed. Now, students are cajoled into communicating their own ideas well, and to demand the same communication from others. A shift has occured from listing skills to be learned toward attributes of classrooms that promote critical thinking as part of the experience of that classroom (Fawcett, 1995; and Makina, 2010).

Such a class to promote critical thinking can be created by providing the conditions for the students to communicate with one another in order to reflect together on the solution to the problem. The first condition is for the students to feel free in expressing their ideas. Then, they must be able to listen attentively to their classmates and show interest in their ideas. So, they communicate both for learning mathematics and in mathematical terms. On the other hand, the students get accustomed to group work, which implies mutual help and cooperation for a mutual aim (Robertson & Rane-Szostak, 1996; Marcut, 2005; and Lee, 2015).

Conceptual Framework. This study is anchored on the belief that critical thinking skills can be learned and should be taught explicitly; and students should be informed about the types of thinking skills taught to them (Swartz, 2001; and McGregor, 2007). Research shows that students' critical thinking skills can be developed, if teachers create a classroom environment that supports the thinking activities (Swartz & Parks, 1994; Rajendran, 2010; and Mason, Burton & Stacey, 2010).

Promoting critical thinking and problem solving in mathematics education is crucial in the development of successful students. Critical thinking and problem solving go hand in hand. In order to learn mathematics through problem solving, the students must also learn how to think critically (Marcut, 2005; and Lee, 2015).

S. Krulik & J.A. Rudnick (1995) stated that critical thinking is analytical thinking and reflection involving testing activities, questioning, connecting, and evaluating all aspects of a situation or problem (Krulik & Rudnick, 1995). To meet the challenge of developing critical thinking in problem solving, there is a need to furnish problem situations that improve students' abilities to communicate their thinking (*cf* Cooper, 1995; Krulik & Rudnick, 1995; CCT, 1996c; and Rajendran, 2010).

W. Szetela (1993), as cited also by Wong

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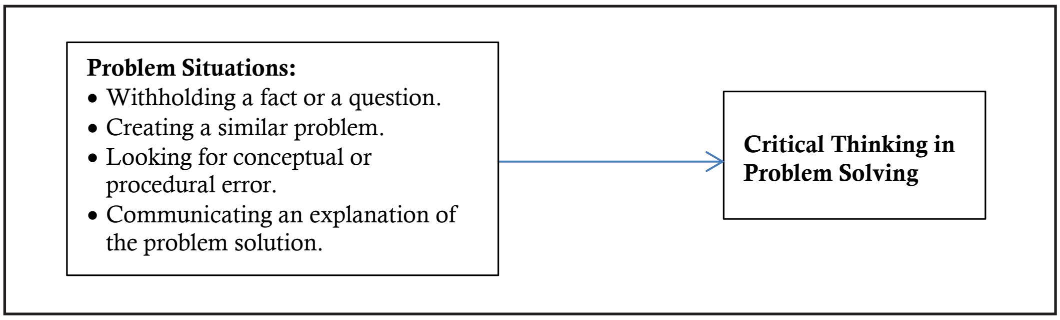

Figure 1:
Conceptual Paradigm

Khoon Yoong (1996), suggested the following ways of developing critical thinking in problem solving: withhold the question or a fact of the problem; after the students have solved the problem, have them create a similar or related problem; present a solution that contains a conceptual or procedural error or a misrepresentation of the problem; and create a problem for which the student must communicate an explanation without actually solving a problem (Szetela, 1993; and Yoong, 1996). The conceptual paradigm of the study is shown figure 1.

The purpose of this study is to effect change on students' critical thinking in problem solving in mathematics using problem situations. Specifically, it tried to answer the following questions: (1) to what extent does the use of problem situations affect the critical thinking in problem solving of the graduate students?; and (2) what are the students' experiences in using problem situations that aim to develop critical thinking?

METHODS

Research Design. The study employed the experimental method, specifically the one-shot experimental design (Campbell & Stanley, 1963; Graziano & Raulin, 1993; Portney & Watkins, 2000; and Beaumont, 2009). A group of fifteen graduate students, who have taken up Educational Statistics were the participants of the study. The experimental period lasted for six weeks. At the beginning of the session, the students were given an open ended test (pre-test) in problem solving that aims to measure their critical thinking. The students were provided activity sheets every session containing problem situations that aim to promote critical thinking in problem solving. At the end of the term, a post-test was administered to the students to measure their critical thinking in problem solving.

Moreover, students' solutions to the activity sheets containing problem situations were analyzed to describe their critical thinking in problem solving. Focus group discussion was also conducted to find out students' experiences regarding the use of problem situations to promote critical thinking in problem solving. The study was conducted on the second term (October – December 2016) of the school year.

Research Instrument. The following research instruments were utilized in gathering the data in this study. Firstly, *Critical Thinking Test*. This is a 10-item open-ended test consisting of typical word problems with supplementary questions designed to encourage communication of critical thinking. This was content validated by three Professors Teaching Educational Statistics.

Secondly, *Scoring Rubric for Critical Thinking Test*. This was used to rate the answers of the students on the Critical Thinking Test. This was content validated by three Professors Teaching Educational Statistics.

Thirdly, *Activity Sheets*. These were used every class session to enhance students' critical thinking in problem solving. These consist of open-ended problems on hypothesis testing. The items in these activity sheets took

Table 1:
Pre-test and Post-test Mean Scores on Critical Thinking

	Pre-test	Post-test	Mean Difference	t-Value	p-Value
Mean	6.68	25.84	19.16	17.24	0.000
Standard Deviation	1.16	4.61			

on any of the following forms: (1) A problem wherein the question or a fact in the problem was withheld, the students examine the problem's facts and conditions, and write their own questions and solutions; (2) Students create a similar or related problem after they have solved a problem; (3) Students are asked to examine the solution to a problem that contains a conceptual or procedural error and they answer a series of questions focused to reveal the extent of their critical thinking; and (4) Students are asked to create a problem for which they must communicate an explanation without actually solving the problem (Graziano & Raulin, 1993; Underwood & Wald, 1995; CCT, 1996a; Portney & Watkins, 2000; and Beaumont, 2009).

Fourthly, *Guide Questions for Focus Group Discussion.* Focus group discussion was done to determine the students' experiences, when using the activity sheets that aim to encourage communication of critical thinking (Robertson & Rane-Szostak, 1996; Portney & Watkins, 2000; and Beaumont, 2009).

RESULTS AND DISCUSSION

Students' Mean Scores on Critical Thinking. Table 1 shows the pre-test and post-test mean scores of the students on the critical thinking test. It can be viewed from the table 1 that there is a significant difference between the pre-test and post-test mean scores. This implies that the use of problem situations enhances students' critical thinking in problem solving (*cf* Cooper, 1995; Beyer, 1995; King, 1995; McDade, 1995; Oliver & Utermohlen, 1995; Cederblom & Paulsen, 2006; and Chukwuyenum, 2013).

Students' Experiences in Using the Problem Situations. The following discussions give the students' experiences on the use of problem situations that aim to enhance critical thinking. When a problem where the question or a fact in the problem was withheld, the students examine the problem's facts and conditions, and wrote their own questions and solutions.

This type of problem situation gave the students the opportunity to think about the given facts and the possible questions that could be asked given these facts. One student gave this comment, as follows:

> *Since problems do not have questions, I was forced to think the corresponding questions for the given problem. I really need to understand the situation to be able to come up with right question to ask* (comment of Respondent A, 10/12/2016).

If students are encouraged to supply the needed facts and the required questions, they think more critically rather than the just requiring them to identify the given facts and substituting these value in the formula to find the unknown (*cf* King, 1995; McDade, 1995; Oliver & Utermohlen, 1995; CCT, 1996b; Cederblom & Paulsen, 2006; and Chukwuyenum, 2013).

Students were also asked to examine the solution to a problem that contains a conceptual or procedural error and they answer a series of questions focused to reveal the extent of their critical thinking (comment of Respondent A, 10/12/2016; comment of Respondent B, 10/12/2016; and comment of Respondent C, 10/12/2016).

This type of problem allows students to think critically by identifying conceptual and procedural errors that the students may encounter and how these misconceptions could be corrected. One student expressed her sentiment regarding this type of problem, as follows:

> *Doing these word problems brought so much fun to me. I wasn't able only to review and apply my learning about hypothesis testing but I was able to entertain myself too by laughing at the errors which were not meant to be done, although some are really confusing but luckily, I was able to come up with the answers* (comment of Respondent B, 10/12/2016).

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This activity gave the students the opportunity to enhance their critical thinking in problem solving. In this context, C. Wade (1995) and other reseachers also believe that problems of this type promotes collaboration, active learning, critical thinking, and multidisciplinary understanding (*cf* Beyer, 1995; Cooper, 1995; King, 1995; McDade, 1995; Oliver & Utermohlen, 1995; Wade, 1995; CCT, 1996b; Jacob, 2012; and Firdaus *et al*., 2015).

Having students construct problems of their own also have benefits, one of the students expressed her sentiments regarding problem posing, as follows:

> *People who knew me last term would never believe these word problems that I personally constructed and answered. I am so happy and excited when I was constructing these word problems, because I was able to apply the knowledge I learned about hypothesis testing. I felt that I am already an expert in statistics* (comment of Respondent C, 10/12/2016).

Open-ended questions and problems can aid the learners in observing how students process mathematics information and also help differentiate the skill level of individual student (*cf* King, 1995; CCT, 1996a; McDade, 1995; Oliver & Utermohlen, 1995; Cederblom & Paulsen, 2006; Jacob, 2012; Chukwuyenum, 2013; and Firdaus *et al*., 2015).

CONCLUSION

The use of problem situations in this study promotes better critical thinking in problem solving among students. It provides better motivation and mechanism for learners to organize their knowledge. Problem situations that require students to demonstrate their declarative knowledge and procedural knowledge are valid in assessing their critical thinking. Moreover, these problem situations develop students' ability to be more reflective and metacognitive, especially when they are analysing problems.

Based on the findings of this study, the following are recommended. Firstly, the problem situations utilized in this study may be tried to other topics in statistics or in other mathematics subjects to determine their validity in enhancing students' critical thinking in problem solving. Secondly, other ways of enhancing critical thinking in problem solving should be developed and tried which are appropriate to a particular type of subjects and students.[1]

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