

# Conceptual and procedural knowledge in problem solving

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## Abstract

This descriptive quantitative study aims to measure students' problem solving in chemistry from four topics of Acids and Bases. It is based on conceptual knowledge and procedural knowledge as well as relations between the knowledge in solving problems. A total of 200 students from four schools in one district were chosen as respondents in this study. Data were obtained through a set of test which measured "Levels of Conceptual Knowledge and Procedural Knowledge". Data were analyzed using descriptive statistics such as frequencies and percentages to determine the appropriate level while relationships among variables were tested inferentially using Pearson Correlation. Proficiency level of students scoring scheme was determined based on the Malaysian Ministry of Education standards. The findings showed that the level of conceptual knowledge and procedural knowledge was weak. The results also indicated that there was a moderate correlation between problem solving based on conceptual and procedural knowledge. Accordingly, science teaching and learning strategies were presented to raise the level of conceptual and procedural knowledge among students.

*Keywords:* conceptual knowledge, procedural knowledge, problem solving, science;

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## 1. Introduction

By the year 2020, Malaysia is expected to be one of the developed countries similar to America, Japan, United Kingdom and others. To be at par with the existing developed countries, Malaysia needs human capital who have a mastery of science and high technology based on the concept of k-economy. Simultaneously, the sixth challenge of Vision 2020 states that science education is one of the key elements that should be addressed in the national education system to order to produce trained and skilled human resources. Furthermore, interest in science education can be a catalyst in an effort to improve the socio-economic development and living standards of people in this country. This claim has been recorded in the statement of Higher Education Planning Committee (1996), "the importance of science and technology in the development of the two resources (human and natural) cannot be looked down upon. A strong foundation in science is important, not only for research but also for development".

Excellence in Chemistry should begin in school if the country wants to produce quality human resources in science and technology. Chemistry is a discipline in science which studies macroscopic and microscopic matter, interaction between materials and production and use of materials (Gilbert and Treagust, 2009). Chemistry as a subject in schools aims to produce students who have the knowledge and skills in Chemistry. In addition, the subject can prepare them to enter the field of chemistry and technology at a higher level. Through Chemistry education, students are guided to develop their intellectual ability to think critically, be creative and innovative. Furthermore, it is hoped that the students will possess the culture of science and technology and able to create a caring, dynamic and progressive society. They will be responsible for environment and have admiration for the creator. Simultaneously, application of knowledge and skills which are based on scientific attitudes and values will enable students to make decisions and solve problems in life more effectively. As a result, they will be able to explore the treasures of nature, adapt to the environment, make innovative creations, and even manage to overcome problems and difficulties. Hence, these visions become one of the goals emphasized in the national curriculum, especially in science education.

## 2. Problem Solving in Education

Jonassen (2003) defines problem solving as an individual thought process because the previously learned law can be applied in solving problems in any situations. It is also deemed to be a new type of learning and is the result of application of knowledge and procedures of the problems (Mc Gregor, 2007). Generally, each individual requires

knowledge and skills to solve problems (Taconis et al., 2000). Halakova and Proksa (2007) states that the solution of problems in any subject area is a highly complex human behaviour. This matter is documented in a large number of studies and articles which have appeared in journals of research and teaching. It has reflected a new interest regarding how students solve problems. Problem solving has always been a stumbling block for students who are studying chemistry, and most of the teachers in the field of chemistry are aware of this.

According to Jawhara (1995), problem solving activities can open opportunities for students to learn freely. In their own ways, students will be encouraged to investigate, seek for the truth, develop ideas, and explore the problem. Students are also trained not to be afraid to try various ways to solve problems, as well as having the courage to make decisions, act on the decisions and be responsible for the products of the action. The experiences gained through problem solving will help our students to become progressive, creative and ambitious. These features are necessary in order to face the challenges of becoming a developed country based on science and technology (Lim et al., 1999).

Problem solving is also deemed to be what is done by an individual when faced with a question or situation where the solution is not available. In seeking a way out from any obstacle, students should think, make decisions and use specific strategies. Therefore, to achieve this, the activity of thinking and skills to rationalize a solution plays an important role. It will require students to generate and induce a systematic and logical thinking. This ability requires students to follow certain steps and logic because it requires a revision to determine the reasonableness of a settlement. Thus, any successful attempt will encourage a students' positive attitude towards problem-solving activities (Curriculum Development Centre, 2006).

According to Reid and Yang (2002), a problem exists when a person feels the gap between where it is and where it should be but do not know how to cross the gap. This broad definition also covers social issues and what might be stereotyped exercises by problem-solving trainers. Students' problem solving abilities is the desired result after going through the process of continuous education as emphasized in the National Education Philosophy and Philosophy of Science Education. Troubleshooting is also the highest hierarchy of learning by Gagne (1997) and problem solving ability reflects the level of student learning. According to Robinson (2003) the ability to solve problems is being considered as an integral part of each science course. In addition to strengthening and clarifying the principles taught in each lesson, systematic approach to problem solving enable students to learn better.

Furthermore, they will have to explain their thoughts and thus promote intellectual development. This ability enhances students' opportunities when they are faced with daily lives problems. Although the benefits of problem solving as an educational tool has long been known, appreciating the skills, techniques and procedures required for effective problem solving have not been adequately taught specifically. This teaching method is significant in order to address and solve problems involving new situations.

### **3. Conceptual knowledge and procedural knowledge in Chemistry Problem Solving**

To solve any chemistry problem, students must have conceptual knowledge and procedural knowledge. The knowledge help students to solve chemical problems such as what they have learned in connection with certain chemical, chemical substances that they have used and they can run experiments to understand the chemical concepts involved. In learning chemistry, the understanding of chemical concepts (conceptual) and problem solving (procedural) is very important. In order to solve any problem correctly, students need both applications of conceptual and procedural knowledge (Cracolice et al (2008) (Figure 1). Furthermore, knowledge is the understanding of conceptual ideas and theoretical chemistry, while procedural knowledge is the understanding of how to apply the concepts learned in any problem-solving situations (Wolfer, 2000). Studies have been conducted in relation to this problem and the results show that although many students were able to solve algorithmic problems, they did not understand the chemistry concepts tested (Chiu, 2001).

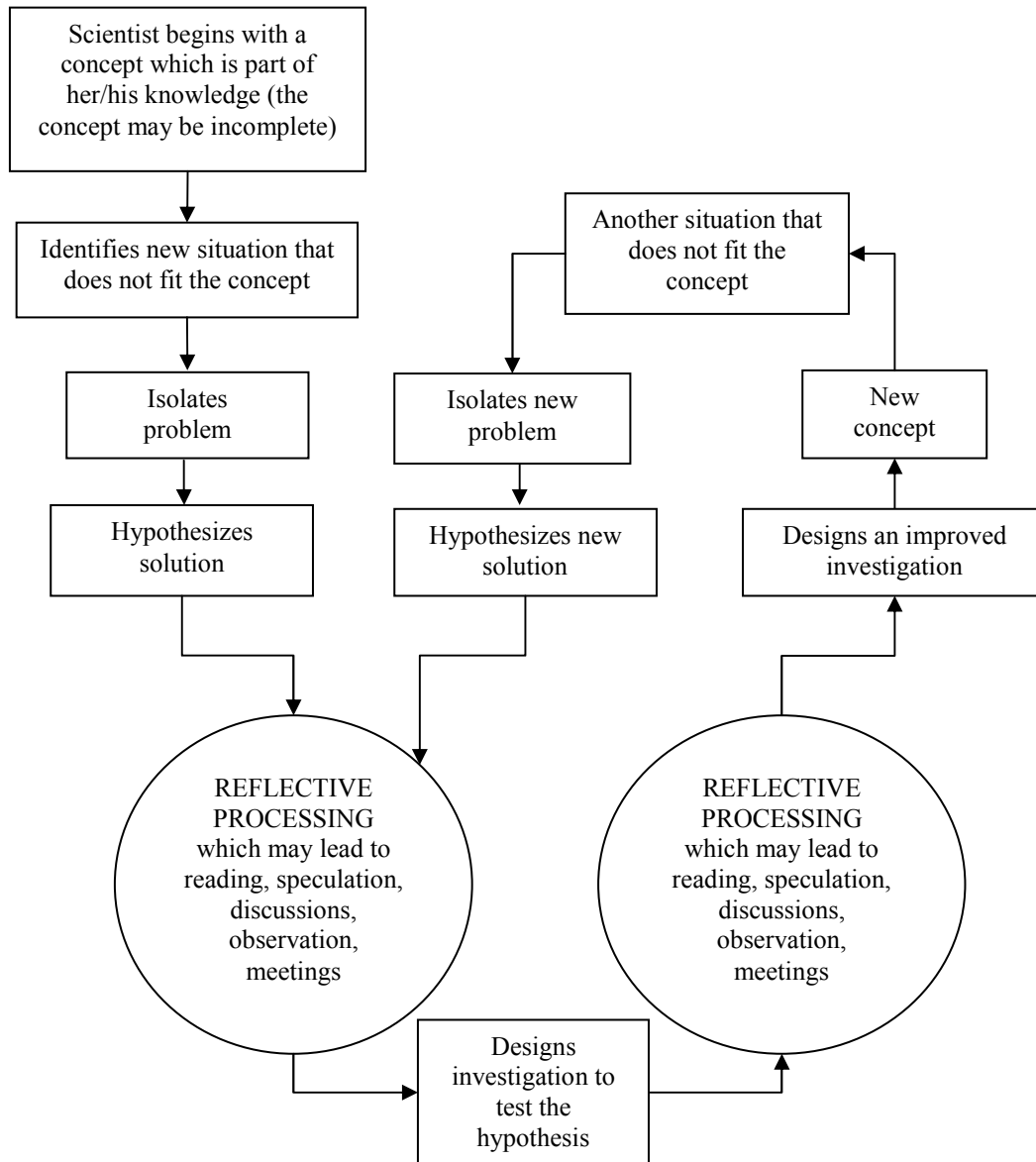


Figure 1. The relationship between knowledge and procedural knowledge

Most students are weak in conceptual knowledge. According to Cracolice et al, 2008) most students continue to rely on algorithm problem solving techniques. Lacking in conceptual understanding resulted in the lack of conceptual usage in solving problems. This claim is shown in a statement that many students can successfully solve problems (by using an algorithm) as compared to answering interview questions based on the concepts involved. It shows that students are only able to memorize and remember the formula and the processes involved without understanding the concepts. This argument is similar to Bunce et al (1990) who studied students with intellectual abilities to solve problems but did not use it effectively. Furthermore, the problem was represented in a manner which was inconsistent with described physical reality. Students who were interviewed after answering these

chemistry questions stated that they did not need to use any conceptual knowledge and understanding in order to solve mathematical problems in chemistry.

Anamuah (1986) conducted a study on high school students in British Columbia whereby they were directed to use the techniques of critical thinking in calculating the concentration of the base after conducting a titration experiment. The data showed that 80% of students used the formula, and 20% of students used the concept of "proportional reasoning" to solve the same problem. Those who used the formula could not show an understanding of the relationship with the constants contained in the formula they used. Although students who used the concept of "proportional reasoning" showed the evidence to examine this relationship, the whole experiment revealed that when students manipulated materials and examined the behaviour of macroscopic, weak links could be made between conceptual understanding and problem solving in chemistry.

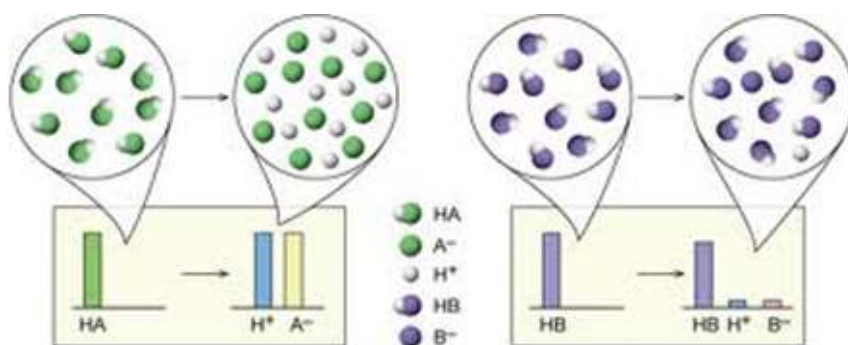
Chemistry is a subject which contains a lot of formulas, rules, principles and issues to be solved. A scientific formula is a brief summary of science and it is useful in solving scientific problems. Scientific formulas may exist in the form of a combination of numbers, letters, and symbols. They are difficult to be learned. Hence, students need to master the conceptual knowledge of chemistry. Students' abilities to recall and select appropriate formula to solve chemistry problems is an ultimate challenge in their lives as students (Aziz and Tai, 2000; Lee et al, 2001).

Selection of correct approaches to problem solving is significant to ensure success. The tasks need to be done systematically and logically. Students should know how to start, where to start, how to analyze and how to find a solution (Selvaratnam 1983). Students also performed poorly in procedural knowledge as described by Wilson (1987), who studied the problem-solving approach in the laboratory, (PSL - problem solving laboratory). It was found that teachers were unconfident and were doubtful to use this technique and preferred to return to traditional methods. According to Zuraidi (1999), students performed poorly in the process of planning for strategies and implementing correct strategies. But they did not encounter any difficulty in understanding the problem. Similarly, a study by Aina (2006) on form four students in Johor Bahru, Johor showed that most of the participants' knowledge of the scientific process was unsatisfactory.

The above discussions indicate that students have various weaknesses in the control of conceptual and procedural knowledge to solve problems in chemistry. Therefore, a study is required to determine the knowledge of students in solving problems. Thus, this research aims to identify the level of conceptual knowledge and procedural knowledge and the relationship between conceptual knowledge and procedural knowledge in solving problems.

#### 4. Methodology

Four schools were selected at random from a population of secondary schools in Johor Bahru. 200 form four students in the science stream were chosen as samples. The study was conducted on form four students because these students have passed Lower Secondary Assessment examination and have achieved the required level of thinking skills. This study used an instrument in the form of a questionnaire consisting of an open test level conceptual knowledge and procedural knowledge (UTPKPP). There are two parts in this questionnaire; Part A covers the questions related to the level of conceptual knowledge of students. Here is a sample of the questions.



The figure above shows the ionization of acids in water. What is the level of acidity in diagram (A) and (B)?

(A): \_\_\_\_\_  
Reason: \_\_\_\_\_  
(B): \_\_\_\_\_  
Reason: \_\_\_\_\_

On the other hand, Part B includes questions related to students' procedural knowledge. All questions are based on Chapter four on the topic of seven levels of chemical acids and bases. Here is a sample question from the set of procedural questions.

- ✓ 0.1 mol dm<sup>-3</sup> aqueous sodium hydroxide (NaOH)
- ✓ 0.1m nitric acid (HNO<sub>3</sub>)
- ✓ A bottle of fenolftalien

You are given the materials above and will carry out the neutralization experiments. In your experiment, please state:

- independent variables
- dependent variables
- procedures for conducting this experiment
- observations from this experiment

Students needed to answer the questions in order to explain the phenomenon and to plan the experiment. Then, students were required to explain their conceptual and procedural knowledge. The results obtained were analyzed using descriptive statistics and inference. Consequently, frequencies and percentages were used to obtain information. Part A and B of UTPKPP consist of 6 questions. Full score for each sub-question is 2. Total full score is 40 and it is multiplied by the percent. As shown in Table 1, the score determines the level of problem solving based on procedural and conceptual knowledge. The scoring scheme is based on the guideline provided by the Ministry of Education.

Table 1: Score level of Problem Solving Based on Conceptual Knowledge and Procedural Knowledge

Score (Percentage)	Level
80 - 100	Excellent
60 - 79	Good
40 - 59	Moderate
20 - 39	Poor
0 - 19	Very poor

To measure the correlation between A and B, SPSS 19.0 for Windows was used to combine both data in this section. In addition, Pearson Correlation Test was used to determine the correlation between conceptual knowledge and procedural knowledge which enabled students to solve problems. The first step was to determine the hypothesis, the null hypothesis and alternative hypothesis. The next step was to set the level of significance and value, determine value and critical areas, and finally did the interpretation. The value of Contingency Coefficients in Table 2 was used to examine the relationship between problem solving based on conceptual and procedural knowledge (Earnest, 1994).

Table 2: Correlation values and descriptions

Value	Description
0.0-0.2	Very weak, negligible
0.2-0.4	Weak, low
0.4-0.7	Moderate
0.7-0.9	Strong, high
0.9-1.0	Very strong, very high

#### 4. Findings and discussion

The findings of this study focused on students' conceptual knowledge, procedural knowledge and the relationship between the two levels of knowledge.

##### 4.1. Students' level of conceptual knowledge

From the analysis of section A in the set of "Test on level of Conceptual and procedural Knowledge" (UTPKPP), conceptual knowledge level of students was determined by taking into account the average percentage of students responded correctly to the questions.

Table 3: Overall Level of Students' Conceptual Knowledge

Levels of concept	Concepts	Percentage of Students Who Responded Correctly (%)	Percentage (%)	Level of achievement
Macroscopic Level	Function of pH in the acid and base	54	34.6	Weak
Microscopic Level	Concept of strong acid and weak acid	34		
	Degree of dissociation of ion	34		
	Neutralization process	36.5		
	Neutralization reaction	14.5		

Part B shows the results for the level of students' problem solving level based on conceptual knowledge. The questions in part B also tested the students at microscopic level. For questions on the macroscopic level which were on the concept of function of pH in acid and base, the level achieved by the students was moderate. Half of the students were able to answer correctly with the percentage of 54% and 59.5%. On the other hand, when the students were asked to answer questions at the microscopic level involving concepts such as the concept of strong and weak acids, the degree of dissociation of ion neutralization process and the neutralization process, less than half of them were able to provide the correct reasons. The data clearly showed that students were weak in solving problems at the microscopic level. On the average, only 34.6% of students were able to provide the correct answers. This finding similar to the results obtained from a study by Tan (2006) which showed students weak performance in the conceptual knowledge.

Conceptual knowledge is the understanding of concepts in the minds of students. Based on a study which tested conceptual knowledge, students' performance was weak. Several factors can cause misunderstanding of concepts such as the existence of alternative framework. According to Johari et al (2011), the existence of various alternative frameworks among students is a result of failure to master science concepts at three levels of knowledge namely knowing of terms, mastery of concepts and problem solving. Therefore, various approaches should be emphasized to reduce the problems in this alternative framework. According to Gilbert et al. (1982) and Kozma and Russell (2007), the level of mastery of concept can be represented in visual form which is easy to understand and explain. Thus, students are able to think on their phenomenon. As a result, students are allowed to overcome alternative framework in their minds more effectively.

##### 4.2. Students' level of procedural knowledge

Part B tested students' science process skills. This section also measured how students conducted activities (experiments) to solve the problems. From the analysis of questions in section B in UTPKPP, procedural knowledge level of students was determined by taking into account the average percentage of students responded correctly to the questions.

Table 4: Overall Level of Students' Procedural Knowledge

Types of skills	Procedural knowledge	Percentage of students who responded correctly (%)	Percentage (%)	Level of achievement
Basic scientific process skills	Classifying	64	31.1	Weak
	Making observation	59.5		
Integrated scientific process skills	Drawing hypothesis	29		
	Controlling the variables	26.5		
	Planning an investigation	12.5		
	Collecting data	24		

The level of students' problem solving in terms of procedural knowledge was weak because less than half of the students (31.1%) were able to answer the questions correctly. More than half of the students managed to answer correctly the basic science process skills involving procedural knowledge of welding and were able to make their own observations with the percentages of 64% and 59.5%. However, less than 30 percent of students had successfully integrated science process skills such as building hypotheses (29%), determining independent variables (26.5%), planning procedures (12.5%) and collecting data (24%). This shows that the students were weak in their mastery of procedural knowledge.

According to Rose et al. (2004), emphasis on students' mastery of science process skills are not regarded as an important element in the process of teaching and learning science. Therefore, the teaching of science does not include the application of students' science process skills. Therefore, high school students performed poorly in studies on mastery of science process skills. Mastery of science process skills or procedural knowledge can be achieved if students are allowed to experience a series where students can have the opportunity to learn about themselves more effectively. Thus, findings by Entepinar and Geban (1996), show that a method of inquiry-oriented laboratory has enhanced students' understanding of scientific concepts. This is because students themselves involved in building hypotheses, designing experimental procedures, data collection, recording observations, making interpretation of data obtained and conclusions.

#### 4.3 Relationship between conceptual and procedural knowledge

To describe the relationship between conceptual and procedural knowledge, the data were analyzed by examining Pearson correlation value ( $r$ ) as shown in Table 5.

Table 5: Correlation Coefficients Between Levels of Conceptual and Procedural Knowledge

	Level of conceptual knowledge	Level of procedural knowledge	Significant
Conceptual		0.687**	0.000
Prosedural	0.687**		

\*\* Significant at the 0.05 significance level (two tailed)

The analysis using SPSS 19.0 for windows indicated that there was a moderate relationship ( $r$  coefficient value was 0687) between the levels of conceptual and procedural knowledge. In addition, the significant  $p$  value of 0000 is smaller than the value at the significance level of 0.05. Therefore, the smaller value of  $p$  rejected the Null hypothesis suggested by researchers. This means that there is a significant relationship between conceptual knowledge and procedural knowledge in solving problems. In solving Chemistry problems, the two types of knowledge are entirely related, although the relationship between the two is at moderate level. Thus, students should master both of them in order to enhance understanding and skills in chemistry. According to Lay (2010) science process skills are closely related to the process used in reading and problem-solving situations in any inquiry. Students will indirectly have a clear understanding of the concept because they have the opportunity to apply the theory learned in class.

## 5. Implications for teaching and learning process

In general, students' problem solving based on conceptual and procedural knowledge was weak because most of the students had alternative framework and had poor control of the microscopic level in the integrated science process skills tested. Therefore, multiple efforts are required to increase the effectiveness of science teaching and learning process in order to overcome students' problems. The teaching of Science based on the concept of change which is generated from the Inquiry approach can overcome the alternative framework as well as increase students' scientific skills. This proposition can be shown in Table 6.

Table 6: Proposed science teaching and learning strategies to enhance students' knowledge of conceptual and procedural

Phase	Science Teaching and Learning Activities
Preliminary phase	Students are presented with cognitive conflict events to uncover the existence of an alternative framework to the concepts presented. It aims to explore the conceptual knowledge of students.
Focus phase	Alternative framework is examined through student's discussion either in groups or individually.
Challenge Phase	Students' alternative framework is challenged through inquiry activities until the students become aware of the alternative framework and thus they form another alternative framework to correct scientific concepts. Through these activities students are exposed to the process of investigation to develop their procedural knowledge.
Application Phase	Scientific concepts that have been built are applied in other phenomena by asking students to perform a variety of other related experiments. It will ultimately help increase the conceptual and procedural knowledge of students.

Through the teaching strategies shown in Table 2, it is expected that teachers will have the capacity to deal with students' problems, especially in developing conceptual and procedural knowledge effectively. These findings thus open a new chapter in scientific research to improve the effectiveness of teaching and learning of Science. Thus, this effort can lead towards strengthening science education and civilization of community.

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