Asian Journal of Chemistry Vol. 21, No. 4 (2009), 3041-3056

Students' Operations of Evoked Concept Images in an Acid-Base Equilibrium System

YILMAZ SAGLAM
Department of Elementary Education, University of Gaziantep
Ilkogretin Bolumu, 27310 Gaziantep, Turkey
Fax: (90)(342)3607268; Tel: (90)(342)3601200/2786
E-mail: ysaglam@gantep.edu.tr

This study confirms the cognitive process in which the students operated a variety of images associated with acid-base concept in an equilibrium system. Sixty two sophomore college students majoring in food science participated in the study in the year of 2007. The students received a questionnaire that involved open-ended items and consisted of 4 parts: (1) questions based on acid-base concept, (2) questions based on chemical equilibrium, (3) questions based on acidity and basicity of an equilibrium mixture, (4) questions based on acidity and basicity of a solution. The data indicated that 23 out of 62 students achieved an appropriate understanding of acid-base definitions and equilibrium concept. However, most students failed to interpret a united context, an acid-base equilibrium system. They operated a variety of inappropriate evoked concept images. To begin with, the students could not consider all their insight related to the problem. Rather, the new context, an acid-base equilibrium system, activated different portions of a concept image and they were mostly inappropriate. Second, while invoking a formal definition accurately, the students seemed to have an inappropriate concept image. Third, the students seemed to quite happily operate a concept image within a particular restricted context, but could not do so within a broader one. Finally, 2 conflicting evoked concept images emerged unconsciously and simultaneously without causing any cognitive conflict.

Key Words: Evoked concept images, Acid-base equilibrium system.

INTRODUCTION

Students encounter with many concepts in some form or another before formal schooling and a complex cognitive structure already exists in the mind of every individual[1], creating various mental images when a concept is evoked. Accordingly, students come to the classroom with many mental images associated with a concept and some may not be in agreement with the current scientific view. Students' inappropriate understandings of scientific concepts are regarded as misconceptions, naive frameworks or alternative conceptions[2-7].

The studies on students' conceptions of acids and bases have revealed the existence of a number of alternative conceptions, including that (1) every neutralization reaction would always produce a neutral solution (pH = 7)[5], (2) a solution of an acid or a base looks like a solution with waves, bubbles or shiny patches indicating that students do not have molecular level view of acids and bases[3], (3) only OH^- ion-producing compounds are bases[8], (4) water is neither an acid nor a base[9], acids are more powerful than bases, (5) neutralization is a simple mixing of acid and base with no interactions between particles, (6) there is no relationship between pH and the hydrogen ion concentration[7], (7) strong acids melt and destroy metals[10] and (8) all acids and bases are harmful and poisonous[10].

The students' alternative conceptions have been attributed to several factors such as social interactions, media[11], student's daily experiences, intuition, chemical symbols or representations[12], chemistry textbooks[7,9,11-13], formal instruction[13], languages in textbooks or instruction[12] and the confusing nature of acid-base definitions or terminology[5,7,11]. However, none of these studies examined the cognitive process of how these alternative conceptions have emerged. Tall and Vinner[1], during the mental process of manipulating a concept, associated properties and processes come into play and consciously or unconsciously affect the meaning or usage.

Tall and Vinner[1], in order to configure how human brain functions, one must distinguish the mathematical concepts as formally defined from the ones constructed with in the mind. A constructed concept that one uses quite happily is not formally defined and might be quite different from its formal concept definition. A constructed concept is usually associated with a symbol, picture or a word, enabling it to be communicated and helps in its mental manipulation. However, the total cognitive structure associated with a concept is far greater than just a symbol, a picture or word. The cognitive structure associated with a concept, called 'concept image' may involve mental pictures, associated properties and processes. It is constructed over the years through experiences of all kinds, alters upon the exposure to new stimuli and develops continuously.

As a concept image develops, the constituting parts of it do not necessarily be coherent at all times[1]. They may conflict with one another. Furthermore, different stimuli can activate different portion of a concept image, which are called 'evoked concept image' (hereafter referred to as ECI). One can operate a different ECI depending on time, context, or problem under consideration. One simply chooses the method (ECI) seemed the most appropriate within the particular context.

The parts of a concept image may also involve seeds of future conflict[1]. That is, one can effectively operate a concept image within a particular restricted context, but could not do so within a broader one. Subtraction, for example, is usually taught at early stages of schooling as a process involving only positive numbers. Exposed to solely positive numbers, students may get a concept image that subtraction of a number always reduces the answer (*i.e.* 5-3 = 2). This is correct, but this image might create problems later on in a broader context because subtraction of a negative number from a positive one yields a greater answer (*i.e.* 5-(-3) = 8).

Students' personal concept definition, which is one part of concept image, refers to form of words that one uses for his own explanations of his/her evoked concept image[1]. A personal concept definition may differ from a formal concept definition. Varying from person to person, a concept definition however generates its own concept image. One might invoke appropriate definitions whilst possessing an inappropriate concept image. This image is the part of the concept image and may not be coherently related to other parts of the concept image. Such a part is called 'potential conflict factor'. If evoked concurrently with other parts, they become 'cognitive conflict factor', which can then create a cognitive conflict. Even a formal concept definition, accepted by the current scientific community at large, itself might be a potential conflict factor and may seriously hinder the learning of a formal theory.

This study aims at examining the cognitive process in which the students operated a variety images associated with acid-base concept in an equilibrium system. The study concerned particularly with how the students employed their concept image of acid-base in an equilibrium context. In the present study, the term 'concept image' refers to students' understanding of acid-base concept. The students' explanations for acid-base concept were viewed as students' evoked concept images (ECIs). In the subsequent part, the equilibrium context in which students' ECIs emerge and the formal definitions for acid-base and acidity-basicity concepts will be elaborated.

EXPERIMENTAL

Equilibrium context: Chemical equilibrium provides students with a valuable framework to understand how chemical systems behave, hence in general chemistry labs, observation of chemical equilibrium systems is a common laboratory activity. In the laboratory, students are generally to add some chemical reagents to an equilibrium solution, observe the changes in the solution, identify the direction of the shift in the equilibrium position and finally explain the phenomenon using the Le Chatelier's Principle. One of the equilibrium systems, for example, involves an acetic acid solution[14]. Since acetic acid has no colour, the students use the bromphenol blue indicator to observe colour changes in acidic and basic solution so that they could determine the shift in the equilibrium position. Accordingly, the students have to test the indicator and identify the colour of the indicator (bromphenol blue) at low and high concentration of H_3O^+. The bromphenol blue indicator has a yellow colour in acidic and blue colour in basic solution.

$$HB + H_2O \rightleftharpoons B^- + H_3O^+$$

Then, the students are to determine the colours of formula HB and formula B. Formula HB is a weak acid and formula B is a conjugate base form of the bromphenol blue indicator. However, most students usually select the wrong colours or provide improper elucidations concerning the direction for the equilibrium position. The students usually claim that formula HB is blue, whereas formula B is yellow. For them, the solution is acidic when the equilibrium position shifts to right because shifting to right will cause formation of more H_3O^+ ions, leading to the production of more formula B and it ultimately dominates the solution and turns the colour of the solution into its own colour, which is yellow.

However, in fact according to Le Chatelier's Principle' that when an equilibrium system is disturbed by adding something to one side, the reaction would respond this by shifting to the other side in order to partially remove some of what had been added. When strong acid HCl is added to the solution, the number of H_3O^+ ions will increase. The reaction would respond this by shifting to the reactants side in order to partially remove some of H_3O^+ ions. This leads the formation of more formula HB, which ultimately dominates the solution and turns the solution into its own colour, which is yellow. On the other hand, when strong base NaOH is added to the solution, the OH^- ions will react with H_3O^+ ions and produce water molecules. This will lead the equilibrium position to shift to products side (the right) forming more of formula B. Ultimately, formula B dominates the solution turning the solution into blue colour, which is contrary to what students had found. As a result, the students for some reasons misinterpreted the equilibrium system and invoked inappropriate utterances. The purpose of this study is therefore to examine the students' cognitive process where the students operated various images associated with acid-base concept in an equilibrium system.

Definition of acid-base concept: In the history of science, scientists have continuously attempted to offer definitions for acid-base concept[9,15,16].

Although these definitions are compatible, they represent progressive expansion of the idea of acids and bases to more types of compounds. At present, only three of them are being considered in common chemistry textbooks-that are, Arrhenius, Brønsted-Lowry and Lewis acid-base definitions[17-27].

According to Arrhenius, acids are substances that produce hydrogen ion (H^+) and bases are those that produce hydroxide ions (OH^-) in water solution[9,15,28]. According to Arrhenius, the degree of acidity for a solution was determined by the concentration of hydrogen ion.

Brønsted and Lowry defined acids as particles that donate protons (H^+) and bases were the particles that accept protons[9,15,16,28] known as Brønsted-Lowry acid-base definition. They considered that acids and bases are to stand side by side. When an acid donates a proton the base receives that proton. As a result of this exchange, the acid turns into a base and the base turns into an acid. The subsequent reaction equation illustrates this phenomenon.

$$HA + B^- \longrightarrow A^- + HB$$
$$Acid_1 + Base_2 \longrightarrow Base_1 + Acid_2$$

In the same year, a more fundamental theory was offered by Lewis. His theory was more inclusive and could be applied to both water included and not included acid-base systems. According to the theory, a base was an electron pair supplier and an acid, on the other hand, was an electron pair acceptor. The following reaction equation illustrates this phenomenon.

$$\underset{\text{Acid}}{H^+} + \underset{\text{Base}}{:OH^-} \longrightarrow \underset{\text{Water}}{H:OH}$$

Acidity and basicity of a solution: The presence of hydrogen (H^+) ions in water solution makes the solution acidic[28]. This fact was first explored by Svante Arrhenius in 1884. The degree of acidity therefore depends upon the concentration of H^+ or H_3O^+ ions in water solution. H^+ and H_3O^+ are different nodes of representation of the same phenomenon. In water solution, H^+ ion bonds covalently to one of the lone electron pairs of the oxygen atom of H_2O molecule to form H_3O^+ ion so in this paper, H_3O^+ is to be used to refer to hydrogen ion in water solution. Moreover, today the concentration of H_3O^+ is usually expressed in terms of pH.

The pH concept was first proposed by Sørensen in 1909, 'hydrogen ion exponent'. When $[H^+]$ is 0.000001 or 1×10^{-6} M, then the pH is 6. According to Sørensen, it became easier to represent the degree of acidity with the pH concept. In particular, pH is equal to $-\log [H_3O^+]$. As the pH decreases, the acidity of the solution increases. However, this definition for pH holds for dilute solutions. It might lead to serious errors when used for concentrated acidic or basic solutions.

Research question: This study aims at examining the cognitive process in which the students operated a variety images associated with acid-base concept in an equilibrium system. In particular, the study had two aims: (1) to experimentally examine the students' cognitive processes from a theoretical perspective offered by Tall and Vinner[1] and (2) to identify the specific ECIs the students employ when interpreting an acid-base equilibrium system.

Design and procedures

Sample description: This study was conducted at a mid-size state university in a large city with an enrollment of approximately 13000 students in 2007. The university is a state university located in southeast Turkey. Sixty two sophomore students who were majoring in food science volunteered to participate in the study. They had completed at least one general chemistry course with a unit on acid-base and equilibrium concepts. Out of 62 students, 23 students achieved an appropriate understanding of acid-base and equilibrium concept. Of these students, 13 students were female and 10 were male.

Methodology: The study was conducted in the spring of 2007. The study aimed at examining the cognitive process in which the students operated a variety images associated with acid-base concept in an equilibrium system. In order to observe the strategies students employ, the students with proper understanding of acid-base definitions and the concept of Le Chatelier's Principle were first chosen. Then, the students were asked to interpret an acid-base equilibrium system after the addition of a strong acid and base and identify the colours of 2 substances so that the strategies the students operated were able to be observed. This was followed by the questions on acidity and basicity concepts.

An open-ended questionnaire was administered to reveal students' conceptions of acids and bases and Le Chatelier's Principle. The questions were adapted from a chemistry textbook[25]. The questionnaire (**Appendix A**) was grouped and categorized under 4 sub-categories. These include: (1) questions on acid-base concept, (2) questions on chemical equilibrium, (3) questions on acidity and basicity of an equilibrium mixture and (4) questions on acidity and basicity of a solution. The questionnaire was piloted 2 times in order to ensure whether wording of the questionnaire items were clear and how much time was required to complete the questionnaire. The questions in the first and second part aimed to probe students' knowledge about acid-base definitions and equilibrium concepts and the questions in the third part explored students' ECIs of acid-base in the context of chemical equilibrium. The questions in the last part explored students' ECIs of acidity and basicity of a solution.

The questionnaire was administered to the students at the end of the Fall Semester. It took *ca.* 40 min for the students to complete it. However, it was observed that out of 62 students, 10 students did not provide complete or clear answers to some of the questions. Accordingly, the author met again those students and conducted short interviews in order to get more insight into their understanding.

RESULTS AND DISCUSSION

The students' written responses and interview transcripts were translated into English and inductively analyzed[29]. In the analysis process, patterns, themes and categories were discovered. The analysis of students' utterances revealed 4 major categories: (1) students' understanding of acid-base concepts, (2) students' understanding of equilibrium concepts, (3) students' understanding of acid-base concepts in the context of chemical equilibrium and (4) students' understanding of acidity and basicity of a solution. Each category is elaborated in the subsequent parts of the paper.

Students' explanations regarding the attributes of acids and bases in water: The students' written and oral utterances were coded based on the categories and operational definitions shown in Table-1. Two additional coders also used Table-1 to code transcripts and an inter-rater reliability of 95 % was calculated, indicating strong inter-coder reliability[30].

Based on operational definitions for acid-base concepts in Table-1, 23 students out of 62 (37 %) established complete and proper responses for the questions in the first and second part. The 23 students properly described the attributes of acids and bases in water solution and were able to explain Le Chatelier's Principle in the equilibrium system. Their ECIs corresponded to the current definitions of acid-base and equilibrium concepts. Table-2 shows summary of the students' utterances about acid-base and equilibrium concepts.

TABLE-1
OPERATIONAL DEFINITIONS FOR CODING CATEGORIES

I. Categories and codes arising from initial descriptions for acid-base and equilibrium concept	
1. Definition	
1.1. Arrhenius definition	Statements that indicate that acids produce hydrogen or hydronium ion, whereas bases produce hydroxide ion in water or aqueous solution.
1.2. Brønsted-Lowry definition	Statements that indicate that acid is a proton donor, whereas base is a proton acceptor.
1.3 Descriptive definition	Statements that indicate that acids have a sour taste; bases have a bitter taste; acids react with bases and produce salt and water; acids turn blue litmus paper into yellow, while bases turn yellow litmus into blue; base has a slippery feel; acids and bases turn organic compounds characteristic colours; and so forth.
2. Examples for acids and bases	
2.1. Symbol	Using such symbols HCl, HNO_3, CH_3COOH, NaOH, NH_3 and the like as examples for acids and bases.
2.2 Everyday life	Statements that illustrate the use of acids and bases in everyday life. Bases can be used for cleaning purposes; fruit and juices contain a variety of acids; sulfuric acid is used in fertilizers, plastics and detergents, *etc*.
3. Acidity and Basicity of a solution	
3.1 Ionization	Statements indicate that strong acids or bases dissociate completely into their ions, whereas weak acids or bases dissociate very slightly into ions in aqueous solution; strong acids or bases ionize almost completely into ions, whereas weak acids and bases ionize feebly into ions in aqueous solution.
3.2 pH Concept	Statements indicate that pH of a strong acid is close to zero and pH of weak acid is close to 7; pH of a strong base is close to 14 and pH of a weak base is close to 7.

In the first part of the questionnaire, the students provided a variety of descriptions and explanations for acid-base concept. To start with, when describing acids and bases, most of the students used Arrhenius acid-base definition. They stated that acids are the substances which produce hydrogen ions and bases produce hydroxide ions in water solution. Second, the students asserted that strong acids and bases ionized almost completely into their ions while the weak acids and bases ionized slightly. Third, most of the students used symbols as examples for acids and bases. They used symbols as HCl, NaOH, NH_3 and so forth. Only few of them provided everyday life examples. Finally, all the students were able to complete the acetic acid-water reaction and appropriately identified acid, base and their conjugates.

Students' understanding of equilibrium concept: All the 23 students appropriately defined Le Chatelier's Principle and stated that if an equilibrium system is

TABLE-2
CHARACTERISTICS OF STUDENTS

Categories		Codes	The number of responses
A. Acids			
	Definition	Arrhenius definition	20
		Descriptive definition	7
	Example	Symbol	22
		Everyday life	4
	Acidity	pH concept	2
		Ionization	21
B. Bases			
	Definition	Arrhenius definition	17
		Descriptive definition	7
		Brønsted-Lowry definition	2
	Example	Symbol	19
		Everyday life	7
	Basicity	pH concept	2
		Ionization	21

disturbed by adding something to one side, the reaction would respond this by shifting to the other side in order to partially remove some of what had been added and appropriately predicted the direction of the equilibrium position. They noted that the following reaction shifted right when Fe^{3+} ion was added to the solution, whereas the reaction shifted left when $FeSCN^{2+}$ ion was added to the solution.

$$Fe^{3+}\,(aq) + SCN^{-}\,(aq) \rightleftharpoons FeSCN^{2+}\,(aq)$$

In summary, in the first and second part 23 students properly described the behaviour of acids and bases and correctly explained Le Chatelier's Principle. These students' concept definition images corresponded to formal concept definitions depicted in Table-1. At this point, one can hypothesize that these students will be able to properly use their understanding of acid-base and equilibrium concepts in interpreting a united context, an acid-base equilibrium system. However, as highlighted in the succeeding parts, this premise has not been robustly supported by the data.

Students' understanding of acid-base concept in the context of chemical equilibrium: In the following equilibrium reaction, 22 students correctly identified formula A and formula B as acid and base, respectively.

$$\text{Formula A} + H_2O \rightleftharpoons \text{Formula B} + H_3O^{+}$$

Regarding the direction of equilibrium position, 17 students indicated that the reaction had to shift to right in order to increase the acidity of the solution. The students stated that when the reaction shifted to right, the numbers of hydronium ions increased, which thereby increased the acidity of the solution because of the hydronium ions. An example includes:

'If the system lies to right, because more H_3O^+ ions are in the system, the acidity of the solution increases. This can be done by adding A or water or by removing B. As a result, we can increase H_3O^+ production'

The students seemed to select and operate an appropriate evoked concept image that hydronium ions made the solution acidic in interpreting the equilibrium system. Another explanation could be that the concept definitions seemed to have generated appropriate concept image for these students. Six students however believed that the reaction had to shift to left because the number of molecules of formula A would increase, due to it being an acid. An example includes:

'If the equilibrium reaction lies to left, the acidity of the system increases because the substance A is acid'

The students incorrectly associated acids with the concept of acidity. They seemed to operate an inappropriate ECI that because the Formula A was acid, it made the solution acidic so the reaction had to shift left. It could be speculated that the different context might have activated different portion of a concept image. The examination of acids and bases in an equilibrium system might have activated the ECI that the Formula A was acid, it made the solution acidic. Another explanation could be that the students might have had an improper concept image of acid-base whilst providing appropriate definitions in the first and second parts. This observation may also support the premise that a formal concept definition itself might be a potential conflict factor. The molecules of HCl, H_2SO_4, NaOH, KOH and the like are formally defined as acids and bases and make a solution acidic or basic. This formal description involves seeds of future conflict. The students are taught that when an acid is dissolved in water, it makes the solution acidic. This insight became misguidance and was not helpful in a broader context, an acid-base equilibrium system.

When asked to determine the colours of formula A and B, the students provided a variety of responses. The students' written and oral utterances were coded based on the categories and operational definitions shown in Table-3. Two additional coders also used Table-3 to code transcripts and an inter-rater reliability of 90 % was calculated, indicating strong inter-coder reliability[31].

Based on operational definitions in Table-3, the students' written responses and interview transcripts were inductively analyzed[30]. Emerging codes or ECIs are depicted in Table-4.

The students' responses revealed that only 2 students appropriately described the phenomenon using concepts from Le Chatelier's Principle. They successfully elucidated the phenomenon and correctly identified the colour of formula A and B as yellow and blue, respectively. The students appeared to believe that adding strong acid causes an increase in the number of hydronium ions, which ultimately caused the equilibrium to shift towards reactants. This increased the number of formula A. Then, formula A had to be yellow and formula B was blue. An example includes:

TABLE-3
OPERATIONAL DEFINITIONS FOR CODES

I. Codes arising from the students' utterances for the colour of formula A and B in an equilibrium system.	
1. Strong acid-hydronium and Strong base-hydroxide source	Statements indicated that adding strong acid causes an increase in the number of hydronium ions, which ultimately caused the equilibrium to shift towards reactants. Similarly, adding sodium hydroxide means adding hydroxide$^-$ to the system, which causes the neutralization of hydronium ions. Thus, the number of hydronium ions decreases. This causes the system to shift to right.
2. Formula A - acidity and formula B-basicity	Statements indicated that raising the number of formula A or formula B make the solution acidic or basic respectively. Or because formula A is an acid, acidity of the solution increases if the equilibrium shifts to left. Similarly, because formula B is base, basicity increases if the equilibrium shifts to right.
3. Formula A-acid and formula B-base	Statements indicated that because formula A is acid, when HCl is added, the equilibrium shifts right and similarly because formula B is base, when NaOH is added, the equilibrium shifts left in order to eliminate the stress.
4. Acids and bases-colour	Statements indicated that acids and bases turn other substances into colours.
5. Hydronium-acidity	Statement indicated that when the acidity of the solution increased, the reaction should shifted to right in order to increase the number of hydronium ions. Similarly, when the solution became basic, the reaction should shifted to left, which resulted in the production of additional molecules of formula A.

TABLE-4
CHARACTERISTICS OF STUDENTS

Codes (ECIs)	Number of Students
Strong acid-hydronium and strong base-hydroxide source	2
Formula A-acidity and formula B-basicity	8
Formula A-acid and formula B-base	4
Acids and bases-colour	2
Hydronium-acidity	1

'Adding HCl is the same thing as adding H_3O^+. Because of this, the system shifts to left. This increases the number of A and H_2O. Because water is colourless and A is dominant, A is in yellow colour. Similarly, adding NaOH means adding OH^- to the system. It neutralizes H_3O^+. Thus, the number of H_3O^+ decreases. This causes the system to shift to right and B becomes dominant and therefore B has blue colour'

The students seemed to select and operate appropriate evoked concept images that adding strong acid causes an increase in the number of hydronium ions, which ultimately caused the equilibrium to shift towards reactants. This increased the number of formula A. Then, formula A had to be yellow and formula B was blue. Another explanation could be that the concept definitions seemed to have generated an appropriate concept image for these students.

However, the rest of the students' failed in interpreting the direction for the position of the equilibrium system and configuring the colours of formula A and B. First of all, 8 students seemed to believe that because formula A was acid, it made the solution acidic. Similarly, because formula B was base, it made the solution basic. If the solution was in yellow colour when it was acidic, then formula A was yellow. If the solution was in blue colour when it was basic, then formula B was blue. The students got the right colours for the wrong reasons. The students once more associated acid and base with the concepts of acidity and basicity. An example includes:

'When the solution became acidic, it turned into yellow. When the solution became basic, it turned into blue colour. Because A is acid, then A should be yellow and because B is base, it should be blue'.

Once again, it seemed that the examination of acids and bases in an equilibrium system activated an inappropriate ECI that because formula A was acid, it made the solution acidic and similarly because formula B was base, it made the solution basic. This finding supports the premise that different stimuli can activate different portion of a concept image. Another speculation could be the students might have had an improper concept image of acid-base whilst providing appropriate definitions in the first part. The students might have had an ECI that acids make the solution acidic whilst invoking that hydronium ions made the solution acidic. Still another conjecture could be that the idea that when dissolved in water, acids make the solution acidic work in water context, but not work in a broader context, an equilibrium system.

Second, 4 students believed that when strong acid was added to the system, the equilibrium position would shift to the right. Since formula A was acid, adding more acids to the system caused the equilibrium to shift to right. This ultimately increased the number of formula B molecules; thereby, the colour of formula B is yellow. Similarly, when strong base was added to the system, the equilibrium position shifted to left. Since formula B was base, adding more bases to the system caused the equilibrium to shift to left. This increased the number of formula A in the solution and thereby the formula A was in blue colour. The students got incorrect colours for the formulas. An example includes:

'When HCl is added to the system, the system shifts to right because A is acid and when we add more acid to the system, the system shifts to right in order to eliminate the stress. Therefore, B becomes dominant and it is in yellow colour. Similarly, when NaOH is added to the system, the system shifts to left in order to eliminate the stress. Thereby, the colour of A is blue'

It can again be speculated that the new context might have caused the students to select and operate an inappropriate ECI that HCl is an acid and the addition of it led the equilibrium shift to right and similarly the addition of NaOH led it to shift left. It seemed that the students did not operate their concept image that the strong acids and bases dissociate almost completely producing hydronium and hydroxide ions in water. Another explanation could be that while the students invoked the belief that the strong acids and bases dissociate almost completely producing hydronium and hydroxide ions, they might have had an inappropriate concept image that HCl and NaOH could be found molecular in an equilibrium system.

Third, 2 students considered acids and bases to have no colour. To them, acids turn other substances into a yellow colour and bases turn other substances into a blue colour. An example includes:

'Both acids and bases have no colour. However, they have the ability of turning other substances into colours. Acids turn other substances into yellow colour and bases turn other substances into blue colour'

It seemed that the students had an ECI that acids and bases turn other substances into colours. It can be speculated that whilst invoking that acids turn litmus paper red and bases turn litmus paper blue colour, the students may have had a concept image that acids and bases were capable of turning substances into colours. It seems this finding supports the premise that while invoking a formal definition accurately, students might have had an inappropriate concept image.

Finally, 1 student considered that when the acidity of the solution increased, the reaction should shifted to right in order to increase the number of hydronium ions. This caused an increase in the number of molecules of formula B. Then, the colour of formula B had to be yellow. Similarly, when the solution became basic, the reaction should have shifted to left, which resulted in the production of additional molecules of formula A. Then, the colour of formula A had to be blue. The following quote taken from student J's transcript illustrates this view.

'When acidity increases, the number of H_3O^+ ions should increase. Therefore, the number of B should also increase. Thus, the colour of B is yellow and the colour of A is blue'

Once again, it seemed that this student employed an inappropriate ECI that the reaction should have shifted right in order to increase hydronium ions and make the solution acidic. This insight might have been helpful within the water context, but was not useful within a broader one, the equilibrium system. This finding supported the premise that one can effectively operate a concept image within a particular restricted context, but could not do so within a broader one.

Six students (26 %) provided neither a clear or nor any explanation for the question. In addition, these students did not want to participate in follow up interviews either.

Students' understanding of acidity and basicity of a solution: In the questionnaire, the students were asked to find out the pH of 10^{-9} M HCl solution. Since there is already a 10^{-7} M H_3O^+ ion concentration coming from the dissociation of water (pure water at 25 ºC), 10^{-9} M H_3O^+ ion concentration coming from dissociation of HCl can be ignored. In other words, we can assume that $10^{-7} + 10^{-9} \approx 10^{-7}$. Therefore, the pH of 10^{-9} M HCl solution is approximately equal to -log [10^{-7}], thus pH ≈ 7.

To determine the pH of 10^{-9} M HCl solution, 10 students thought that the pH is equal to 9 and the solution is basic. It seemed that the students employed an inappropriate ECI that strong acids completely dissociates into ions and made the solution acidic. Therefore, the pH of 10^{-9} M HCl solution is 9 and the solution is basic.

Six students however reported that the pH of the solution is equal to 9 and the solution was weakly acidic because the concentration of acid was very low. It seems that the students concurrently and unconsciously operated 2 conflicting ECIs that (1) strong acids completely dissociates into ions and make the solution acidic. Therefore, the pH of 10^{-9} M HCl solution is 9 and (2) because the concentration of acid is very low, the solution is slightly acidic. Therefore, the pH should slightly be lower than 7. The students seemed not to realize that these 2 beliefs were conflicting with one another. These 2 beliefs are cognitive conflict factors, but because the students unconsciously operated them, they did not cause cognitive conflicts.

Three students believed that the pH of the solution was 9 but could not make any comments on it. It can be speculated that the students concurrently and consciously operated 2 conflicting ECIs that (1) strong acids completely dissociates into ions and make the solution acidic. Therefore, the pH of 10^{-9} M HCl solution is 9 and (2) because the concentration of acid is very low, the solution is slightly acidic. This might have created a cognitive conflict and prevented them to provide an explanation for the phenomenon.

Two students employed appropriate ECI that because the concentration of strong acid was very low, the hydronium ions should mostly have come from the dissociation of water. Therefore, the pH of the solution could not be 9 but should be lower than 7. Finally, 2 students did not answer this question.

Conclusion

In conclusion, a number of assertions could be made regarding the cognitive process through which the students operated various images associated with acid-base concept in an equilibrium system. First of all, the students could not consider all their insight related to a problem. Rather, different context or problem activated different portions of a concept image (ECI) and they were mostly inappropriate. When the students were, for example, asked to predict the direction of the equilibrium position when the solution is acidic, some of them selected and operated an inappropriate ECI that Formula A made the solution acidic so the reaction should have shifted left. It seemed that the students did not operate their concept image invoked in the first part of the questionnaire that hydronium ions made the solution acidic.

Second, while invoking a formal definition accurately, students might have had inappropriate concept image. When the students were asked to configure the colours of formula A and B, it seemed that the students had an ECI that acids and bases turn other substances into colours. It can be speculated that whilst invoking that acids turn litmus paper red and bases turn litmus paper blue colour, the students may have had a concept image that acids and bases were capable of turning substances into colours.

Third, one can quite happily operate a concept image within a particular restricted context, but could not do so within a broader one. When the students were asked to find out the colour of formula A and B, 1 student considered that when the acidity of the solution increased, the reaction should have shifted to right in order to increase the number of hydronium ions. This caused an increase in the number of molecules of formula B. Then, the colour of formula B had to be yellow. This ECI that the number of hydronium ions determines the degree to which a solution is acidic might have been helpful within the water context, but was obviously not useful within a broader one, the equilibrium system.

Finally, 2 conflicting ECIs emerged unconsciously and simultaneously without causing any cognitive conflict. When the students were, for example, asked to determine the pH of 10^{-9} M HCl solution, they invoked two conflicting ECIs that (1) strong acids completely dissociates into ions and make the solution acidic. Therefore, the pH of 10^{-9} M HCl solution is 9 and (2) because the concentration of acid is very low, the solution is slightly acidic. The students seemed not to realize that these two beliefs were conflicting with one another so a cognitive conflict did not occur. However, 3 students could not make any comments on the acidity of the solution. It seemed these students had a cognitive conflict.

In conclusion, the results supported the notion that: *'the human brain is not a purely logical entity. The complex manner in which it functions is often at variance with the logic of mathematics. It is not always pure logic which gives us insight, nor is it chance that causes us to make mistakes. To understand how these processes occur, both successfully and erroneously, we must formulate a distinction between the mathematical concepts as formally defined and the cognitive processes by which they are conceived'* [1].

Appendix

The Questionnaire for Students' Conceptions of Acids and Bases in the Context of chemical equilibrium

Section I: Properties of acids and bases:

1. Can you please describe the properties of acids?
2. How do you define an acid?
3. Please give me some examples.
4. How do you recognize a strong and a weak acid?

If no answer, then ask: What makes an acid weak or strong?

5. What would you tell me about the acidity of the following acids?

HCl and CH_3COOH (acetic acid)

6. Can you please describe the properties of bases?
7. How do you define a base?
8. Please give me some examples.
9. How do you recognize a strong and a weak base?

If no answer, then ask: What makes a base weak or strong?

10. What would you tell me about the basicity of the following bases?

NaOH and NH_3

11. Please complete the following reaction:

$CH_3COOH + H_2O \rightleftharpoons$ ……… +. ……..

a. Can you identify acids and bases?

b. What does the double arrow stand for?

Section II: The concepts from Le Chatelier's Principle:

12. Can you please explain what Le Chatelier's Principle is?
13. Look at the following reaction.

Fe^{3+} (aq) + SCN^{-} (aq) $\longrightarrow$ $FeSCN^{2+}$ (aq)

a. Please predict what you should observe when Fe^{3+} ion is added to the solution. Explain your answer using concepts from Le Chatelier's Principle.

b. Please predict what you should observe when $FeSCN^{2+}$ ion is added to the solution. Explain your answer using concepts from Le Chatelier's Principle.

Section III: The acidity or basicity of an equilibrium system:

14. Please look at the following equilibrium reaction. In this reaction, formula A reacts with water and produce formula B and the H_3O^+ ion.

Formula A + H_2O $\longrightarrow$ Formula B + H_3O^+

a. Can you identify weak acid and base in this reaction?

b. In which direction this reaction must shift in order to increase acidity? Explain your answer using concepts from Le Chatelier's Principle.

c. When we added 6 M HCl solution into this system, the solution became acidic and it turned into red colour. When we added 6 M NaOH solution into this system, the solution became basic and it turned into blue colour.

From these observations, what do you think what the colours of the formula A and formula B could be? Explain your answer in detail.

Section IV: The acidity or basicity of a solution:

15. What is the pH of 10^{-9} M HCl solution? What can you tell about the acidity of this solution?

16. What makes a solution acidic?

17. What makes a solution basic?

REFERENCES

1. D. Tall and S. Vinner, *Educ. Stud. Mathemat.*, **12**, 151 (1981).
2. D.R. Mulford and W.R. Robinson, *J. Chem. Educ.*, **79**, 739 (2002).
3. M.B. Nakhleh, *J. Chem. Educ.*, **69**, 191 (1992); **71**, 495 (1994).
4. M.B. Nakhleh, A. Samarapungavan and Y. Saglam, *J. Res. Sci. Teach.*, **42**, 581 (2005).
5. H.-J. Schmidt, *Sci. Educ.*, **8**, 123 (1997).
6. K.J. Schoon and W.J. Boone, *Sci. Educ.*, **82**, 553 (1998).
7. K. Sheppard, *Chem. Educ. Res. Prac.*, **7**, 32 (2006).
8. S.J. Hawkes, *J. Chem. Educ.*, **69**, 542 (1992).
9. M. Drechsler and H.-J. Schmidt, *Chem. Educ. Res. Practice*, **6**, 19 (2005).
10. G. Demircioglu, H. Ozmen and A. Ayas, *Educ. Sci., Theory & Practice*, **4**, 73 (2004).
11. M.H. Chiu, *Chem. Educ. Internat.*, **6**, 1 (2005).
12. J.W. Lin, M.H. Chiu and J.C. Liang, Exploring Mental Models and Causes of Students' Misconceptions in Acids and Bases [On-line]. Available: http://science.gise.ntnu.edu.tw/profile/workshop/NARST2004full%20text0213acid%20and%20base.pdf (2006).
13. S.J. Hawkes, *J. Chem. Educ.*, **71**, 747 (1994).
14. Chemistry 116 Laboratory Manual, Hayden-McNeil Publishing, Chemistry Department, Purdue University, Indiana (2004-5).
15. D. Kolb, *J. Chem. Educ.*, **55**, 459 (1978).
16. M. Kousathana, M. Demerouti and G. Tsaparlis, *Sci. Educ.*, **14**, 173 (2005).
17. M. Bishop, An Introduction to Chemistry, Benjamin Cummings, New York, edn. 1 (2002).
18. T.L. Brown, H.E. LeMay and B.E. Bursten, Chemistry: the Central Science, Prentice Hall, New Jersey, edn. 7 (1997).
19. R.A. Burns, Fundamentals of Chemistry, Prentice Hall, New Jersey, edn. 3 (1999).
20. C.H. Corwin, Introductory Chemistry: Concepts and Connections, Prentice Hall, New Jersey, end. 2 (1998).
21. M.D. Joesten and J.L. Wood, World of Chemistry, Saunders College Publishing, New York, end. 2 (1996).
22. J.W. Moore, C.L. Stanitski and P.C. Jurs, Chemistry: the Molecular Science, Harcourt College Publishers, New York, edn. 1 (2002).
23. R.H. Petrucci and W.S. Harwood, General Chemistry: Principles and Modern Applications (7th ed.), Prentice Hall, New Jersey (1997).
24. S. Russo and M. Silver, Introductory Chemistry, Benjamin Cummings, New York (2000).
25. M.S. Silberberg, Chemistry: the Molecular Nature of Matter and Change, McGraw-Hill, New York, edn. 3 pp. 756-797 (2003).
26. J.A. Suchocki, Conceptual Chemistry: Understanding our World of Atoms and Molecules, Addison Wesley, New York (2001).
27. N.J. Tro, Introductory Chemistry, Prentice Hall, New Jersey (2003).
28. D. Kolb, *J. Chem. Educ.*, **56**, 49 (1979).
29. M.Q. Patton, Qualitative Research and Evaluation, Sage Publications, London. pp. 75-138, 453-54 (2002).

(*Received*: 4 July 2008; *Accepted*: 21 January 2009) AJC-7158