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Assessing Conceptual Change Instruction Accompanied with Concept Maps and Analogies: A Case of Acid-Base Strengths

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ABSTRACT

The research assessed secondary school students' conceptions of acid-base strengths by using the conceptual change instruction accompanied with concept maps and analogies. These teaching strategies were employed to help them make unfamiliar events familiar. Within a quasi-experimental design, the sample of the study consisted of 73 secondary school students. Pre- and post-tests were used to collect data. The results showed that the experimental group that took the conceptual change-oriented instruction performed better than the control group. In light of the results, it can be concluded that employing such visuals and interactive materials as concept maps and analogies for achieving conceptual change is effective in generating better understanding of chemistry concepts.

Key words: Analogy, conceptual change, concept mapping, misconception, visualization

INTRODUCTION

Chemistry education systematically handles how to acquire fundamental knowledge about the universe. It concerns itself with the acquisition of knowledge on the properties, interactions and transformations of matter. It further seeks to act as a bridge between students' preconceptions of the world and scientific concepts (Barke, Hazari, & Yitbarek, 2009). Thus, students should be allowed to express their naïve worldviews in the class. By doing this, they are able to unveil their alternative conceptions of chemical changes. These prior conceptions help teachers to strategize and create relevant context that activate 'a need to know' (Ultay & Calik, 2016) situation before new scientific ideas are introduced. In the view of Taber (2001), such alternative conceptions are very common in many areas of science. Physics students generally hold alternative conceptions about force, work and energy, while biology misconceptions mostly concern the origin of the matter in plants and cell. Similarly, chemistry students think that the nucleus of an atom conveys

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a certain amount of attractive force, which is shared between the electrons in the atoms. Since chemistry is a mainstay of science, technology and industry, it should be taught in a meaningful learning manner to minimize any alternative conception, from a more conceptual change-oriented point of view. Conceptual change deploys students' pre-existing conceptions as a necessary framework to solve problems, explain phenomena and functions in their world (Cetingul & Geban, 2005).

Any discrepancy between students' pre-existing conceptions and new concepts arouses conceptual conflicts, which need to be changed prior to further learning (Hanson, Kwarteng, & Antwi, 2015). A lot of researches have elicited students' misconceptions in such chemistry topics as particulate nature of matter (Chandrasegaran, Treagust, & Macerino, 2007), chemical equilibrium (Bilgin, 2006), acids and bases (Abanga, 2015; Ultay & Calik, 2016), mole concept, and chemical and physical changes (Hanson, Twumasi, Aryeetey, Sam, & Adukpo, 2016). For the acid-base topic, Pinarbasi (2007), who found out Turkish undergraduate students' conceptions of acids and bases, showed a number of implications for tertiary level teaching. Similarly, Yalcin (2011) depicted that science student teachers at different grades had misconceptions of acid-base concepts. Also, he did not find any significant difference between the grades from the first-year to the fourth-year one. This means that students at all grades and student teachers have similar misconceptions of acid-base chemistry. However, identifying students' misconceptions is not enough to overcome them or attain conceptual change (Hanson, 2018). For example; Say and Ozmen (2018) used concept cartoons to decrease Turkish students' alternative conceptions of the structure and properties of matter. However, few studies have been concentrated on the use of conceptual change to enhance conceptual understanding at a specific grade in the African continent.

Acid-base concepts are fundamental for chemistry to explain most chemical interactions in the environment and human body. Cros and Maurin (1986), who examined the first-year students' misconceptions of acid-base topic, found that most of them thought that acids were more dangerous than bases. Banerjee (1991), who developed a test to diagnose students' misconceptions of acid-base equilibrium, found that the students viewed that rain water was neutral. Similarly, they implied that pH of the ethanoic acid would be less than or equal to the pH of hydrochloric acid solution in water. Boz (2010), who obtained Turkish chemistry student teachers' alternative conceptions of acids and bases, found that most of them did not have challenges with macroscopic properties, neutralization, and distinction between 'strength' and 'concentration' of acids and bases. Hanson's (2011) findings on acid-base concepts showed that elementary school students saw all acids as strong and powerful burning substances. They also added that all acids, except for those in fruits, were poisonous. Bradley and Mosimege (1998), who studied student teachers' conceptions of acid-base topic, revealed that they did not consider indicators as a necessary for the presence of basicity or acidity even though they could be used to test acid strength. Bradley and Mosimege (1998) also found that their students intimated that aqueous solutions of all salts as neutral. These studies have suggested that students bring their pre-conceptions to class. This needs to employ conceptual change approaches remedying alternative conceptions. For example; Ozmen, Demircioglu and Coll (2009), who exploited laboratory activities accompanied with concept mapping (which is a conceptual change approach), reported a better understanding of the acid-base chemistry.

Conceptual change is viewed as a process of replacing misconceptions with scientific ones. Using conceptual change strategies helps students to re-construct their ideas and/or pre-conceptions. Analogy is another effective strategy in overcoming misconceptions. It helps students to learn new information as they discard or modify misconceptions in scientific ways. New materials then become more intelligible to students as compared with familiar materials. For instance; Cetingul and Geban (2011), who combined a ribbon analogy with concept maps and conceptual change approach to explain valences in the acid-base topic to the Turkish students, depicted that this social framework helped them to create a model of the molecular world (Cetingul & Geban, 2011). Analogies can be seen as anchors to conceptual bedrocks. There is an explicit effort to make unfamiliar familiar. In using analogies, students construct their own knowledge and apply them to new situations. Stavy (1991) stated that using analogy to overcome misconceptions about *conservation of matter* was an effective tool in teaching chemistry.

The use of concept maps as a teaching strategy is also very helpful to promote conceptual understanding as found by Aydin, Aydemir, Boz, Dindar and Bektas (2009) and Ozmen, Demircioglu and Coll (2009). A concept map, which is a useful graphical representation, can be used for any information on nodes and propositions. A central concept firstly is identified, and then linked with each other concepts. Later, concise and familiar concept labels are used. In case of concepts of different generality, more general concepts are centrally located. More specific concepts are peripherally placed on the concept map. Concept maps are flexible tools that help to represent one's knowledge. It allows students to visualize knowledge in graphical form and to makes retention and recalling easier. Besides, it positively impacts on their affective and psychomotor domains. They are also used as diagnostic tools to elicit students' knowledge structures and frameworks. Investigating students individually to elicit their problems may be intimidating and time consuming. To deploy a more time-efficient and less stressful approach, students are asked to prepare their own concept maps. Hence, they are able to reveal their alternative conceptions, integrated ideas and the extent of interlinks at key ideas. Concept maps are in a harmony with tenets of constructivism. For example; Taber (1994), who employed concept mapping, found positive conceptual gains and stimulated their interests and motivated engagements.

Constructivist science teaching focuses on what is discovered in the process of learning and requires actively first-hand experiences. Students' pre-existing knowledge may hamper their efforts to achieve conceptual understanding towards the accepted scientific view even though they are very active in constructing knowledge. Overall, identifying students' prior conceptions before teaching could act as a bridge linking what they have known in a more affable way with the targeted one. For such educational purposes, diagnostic tests are used to elucidate students' own ideas of science concepts (Bayrak, 2013). Hence, diagnostic tests help science/chemistry educators to gain insights into students' conceptions.

Purpose

This study purposed to examine grade 11 students' prior conceptions of acid-base topic and the effect of conceptual change instruction accompanied with analogies and concept maps on their conceptual understanding of the acid-base concepts.

Research Questions

1. What prior conceptions do students have about acids and bases?
2. Is there any significant difference between the conceptual change instruction and traditional instruction in remedying the students' misconceptions of the acid-base topic?
3. What do the students in the experimental group think about their engagement with concept maps and socio-scientific analogies?

METHODOLOGY

Within a pre-test, post-test, control group design, the sample of the study comprised of 73 Grade 11 students drawn from two different schools. Two different teaching methods, which lasted three weeks, were randomly assigned to the schools. The experimental group (N: 36) received conceptual change lessons oriented with concept maps and real life-based analogies. The control group (N: 37) was exposed to teacher-centered instruction called traditional or didactic teaching. Ultay and Calik (2016) had carried out a similar study with three groups of pre-service science teachers using different teaching designs (REACT strategy, 5Es model and traditional instruction). They employed Acid-Base Chemistry Concept Test (ABCCT). Given a blend between a Turkish model by Calik and Ayas (2005) and a Thai model by Artdej, Ratanaroutai, Coll and Thongpanchang (2010), an acid-base diagnostic test (ABDT) was adapted and administered after ensuring validity and reliability. The diagnostic test was designed to unveil and measure students' naïve conceptions and conceptual understanding of acids and bases. Thus, its open-ended construction gave them an opportunity to express their own innate conceptions. To sum up, a 15-item multiple choice diagnostic test was developed from the gathered misconceptions.

The test was firstly pilot-tested with a different school, which had similar characteristics with those in the real study. In view of Meriwether (2001), the pilot study enhances the reliability of instrument. The 15-item diagnostic test was based on misconceptions depicted by Taber (2001) and Bradley and Mosimege (1998). The content validity of the instrument was confirmed by three senior chemistry colleagues. Cronbach's alpha coefficient (Cronbach, 1951) was used to calculate the reliability of the instrument (diagnostic test in this case). Its Cronbach alpha reliability was found to be 0.76, which indicates an acceptable reliability of an instrument suggested by Bryman (2008). Some common misconceptions reported in the related literature were also employed to construct the ABDT.

Procedure

The study purposed to compare the effectiveness of conceptual change-oriented instruction on Grade 11 students' understanding of the acid-base concept with traditional one. The study was conducted in two public high schools in Cape Coast, Ghana. The ABDT was administered as a pre-test before the teaching intervention. Then, the same test was re-administered as a post-test after the teaching treatment. Hence, the study intended to determine any significant difference between them. The control group was instructed with traditional methods (i.e., lecture, discussion and solving algorithmic problems) suggested by the Ministry of Education. A summary of the day's lesson was written as core points. Hence, students copied them. Their attention was carefully drawn to important facts, equations, and symbols. The experimental group was taught via the interactive and student-centered approach. They were exposed to clearly some common misconceptions of acids and bases. Hence, they analyzed them through probes and discussions, which resulted in re-structuring their conceptual understanding. In this study, the students were specifically asked about the strengths of acids. A 15-item diagnostic test was handed out to all students again at the end of the treatment period. Each item was scored with a point.

RESULTS and DISCUSSION

Percentages of grade 11 students' misconceptions in the pre- and post-test are shown in Table 1.

Table 1: *Percentages of* ***misconceptions*** *in the pre- and post-test for the experimental and control groups*

Misconceptions	The experimental group (N: 36)				The control group (N: 37)			
	Pre-Test		Post-Test		Pre-Test		Post-Test	
	f	%	f	%	f	%	f	%
1	12	33.3	4	11.1	14	37.8	7	18.9
2	9	25.0	1	2.8	7	18.9	2	5.4
3	10	27.8	0	0.0	11	29.7	4	10.8
4	8	22.2	0	0.0	7	18.9	2	5.4
5	4	11.1	2	5.6	6	16.2	3	8.1
6	21	58.3	1	2.8	19	51.4	1	2.7
7	18	50.0	8	22.2	19	51.4	11	29.7
8	14	38.9	3	8.3	17	46.0	8	21.6
9	13	36.1	1	2.8	11	29.7	7	18.9
10	14	38.9	0	0.0	15	40.5	9	24.3
11	17	47.2	3	8.3	13	35.1	7	18.9
12	26	72.2	1	2.8	27	73.0	15	40.5

f = frequency

The results of independent samples t-test showed no significant difference between the groups' pre-test mean scores of the ABDT. This means that their pre-conceptions were almost equivalent at the beginning of the study ($t=2.07$, $p>0.05$). They could identify very simple properties about acids and bases such as acids being sour and bases being bitter. Further, the experimental and control groups had similar misconceptions of acids and bases at especially sub-microscopic and symbolic levels. Indeed, the same thing was valid for macroscopic properties (Boz, 2010; Pinarbasi, 2007). For example; the students thought that the pH value of ethanoic acid (CH_3COOH) was higher than that of ammonia (NH_3) solution. The students further iterated that pH values of acids were greater than those of bases. They also intimated that ammonia was a stronger base than sodium hydroxide (NaOH) because it had more hydrogen atoms. That was a misinterpretation in identifying the bases.

The results of independent samples t-test revealed a significant difference between the experimental and control groups' post-test mean scores of the ABDT in favour of the experimental ones ($t=2.07$; $p<0.05$). The experimental group scored higher marks than did the control one. The retention percentage of the misconceptions in the experimental group was 1.85 in the post-test (which had been improved from 13.83% in the pre-test), while that of the control group was 5.55 in the post-test (which had been evolved from 13.83% in the pre-test). Some of the scientific conceptions identified by earlier Turkish and Thai studies are as follows:

1. Strong acids completely ionize while weak acids partially ionize in aqueous solutions
2. Concentrated acids contain higher moles of acidity to volume of solution
3. Strong acids can form dilute solutions if their amounts are small as compared with the volume of water
4. HNO_3 is a stronger acid than HCOOH because all molecules of HNO_3 completely ionize

Furthermore, new ideas elicited by the current study are in the following:

1. NaOH is a stronger base than NH_3
2. NaOH has a higher pH than NH_3
3. NaOH and KOH are strong bases because they have higher concentrations of OH^- ions
4. Strong bases completely ionize to produce many OH^- ions while weak bases partially ionize at molecular level.
5. NaOH has a higher pH while NH_3 has a lower pH

Students construct new knowledge with prior knowledge (Cetingul & Geban, 2011). It is always important to consider and collate their prior knowledge on all topics before teaching them. Identified alternative conceptions should be discussed through a teacher's guidance to unveil familiar relationships so that students can socially form their own scientific ideas. Pointing out their misconceptions without any intervention and/or treatment does not help to achieve conceptual change. Meaningful learning requires to actively engage students in problem-solving situations, critically think and re-organize old ideas with new ones. Thereby, based on their prior knowledge, they test their ideas and approaches to construct new knowledge. Also, they apply newly generated knowledge to novel situations by meaningfully linking their new knowledge to the existing conceptual frameworks (Aydin, Aydemir, Boz, Centin-Dindar, & Bektas, 2009).

This current study planned lessons and materials about the acid and base concepts with flexibility given grade 11 students' naïve ideas. The three-week treatment helped them to acquire a deeper understanding and better visualize the concepts. Because basic visualization depends on the operations of metaphors and analogies, analogical reasoning in the current study afforded them to review/revise their prior knowledge, realize their common misconceptions and then correct them. Since the use of analogies served as a bridge between everyday life phenomena and classroom science, it engendered a better conceptual understanding. For example; they were able to make comparisons amongst HCl, H_2SO_4 and H_3PO_4, by analyzing the relationship(s) between the number of hydrogen atoms (in reality H^+ ions) in an acid and its acid strength. Majority of them answered that H_2SO_4, which had more hydrogen atoms, would have a higher acid strength. They intimated that H_2SO_4, which contained one more hydrogen atom, would have twice the strength of the HCl acid, and H_3PO_4 would have three times that of HCl, which had only one hydrogen atom. This is not true in reality, as regarded by scientific findings.

Analogies had to be provided for students to appreciate that sometimes one bulb, as in the compact fluorescent lights, sometimes one bulb for students. That is, the compact fluorescent lights could give more light in that they are more powerful than two or three tungsten 'onion' bulbs of the same capacity. If we link this analogy again to the acid strength and number of hydrogen atoms, HCl is a stronger acid than H_2SO_4 because it gives off more hydrogen ions to the water than the latter one. Such answers were probed through guided questions until a correct answer was arrived at. Then, to establish real-life analogical reasoning experiences, they were asked to respond the question 'How do you determine the strengths of bulbs at home, without reading the inscribed wattage.' They indicated that the brightness of the light could be used. 'If a bulb gave off a lot of light, it was stronger than one with little light'. These findings were similar to what Boz (2010) found among Turkish chemistry student teachers. Namely, like the Turkish students, these Ghanaian students did not have much difficulty with macroscopic properties of the acids and bases but they possessed pitfalls in comprehending the distinction between 'strength' and 'concentration' of the acids and bases.

Unlike previous studies, the students under investigation were able to use the degree of ionization and the presence of the hydroxyl ion (OH^-) for classifying the strengths of the acids-bases. That is, a base will be strong and light up a bulb with intensity or be weak and light up a bulb with less intensity. Thus, the students were able to build concept maps about the strengths of bases after analogical discussions for the acids. They distinguished the strengths of the bases in the solutions of ammonia and sodium hydroxide with scientific reasons. Further, they used examples from everyday life to support their claims.

Students were also encouraged to use concept maps to express any ‘acid-base’ idea. The use of concept maps generated a lot of excitement (Taber, 1994; Ozmen, Demircioglu, & Coll, 2009). Each group tried to relate some of their linkages/propositions to real life situations. They were promoted to select their own analogies from their close environments. For example; the students chose such examples as lemon on their concept maps of the acids. Other students also used plantain ash (KOH/ NaOH) to produce a salt. This helped them to form realistic relationships between their used terminologies and scientific ones. Hence, they discussed the acid-base concept to enable them to do away with any confused difficult concept. Since the acid-base topic includes inter-related concepts, they should be taught through appropriate constructive approaches to avoid misconceptions hindering further chemistry learning (Bayrak, 2013; Boz, 2010).

The teacher in the current study acted as a facilitator to promote the students to freely interact with each other and form their own concepts using pre-existing knowledge. The ‘dim and bright bulbs’ analogy seems to have often been more useful than didactic instruction with a thousand words.

CONCLUSIONS and IMPLICATIONS

The traditional instruction was ineffective in in eliminating the students’ misconceptions of the acid-base topic (Andre & Chamber, 1997; Mikilla, 2001; Hanson, 2011; Abanga, 2015). In fact, it is believed that the traditional method only attempts to transmit teacher’s knowledge to his/her students in a uni-dialogical stream, and does not relate school knowledge to everyday life. Teachers act as the persons ‘knowing all.’ But, conceptual change approaches take student-centered learning into account and enable them to cultivate their own ideas facilitating to re-construct the scientific knowledge/ideas as was also found by Ultay and Calik (2016). If students are not systematically forced to consider their worldviews, they will integrate new content into them. However, addressing their misconceptions and acknowledging their pitfalls in their thinking make their minds more affably to new content/knowledge. Therefore, teachers should become aware of alternative teaching strategies allowing to collate and remedy their students’ prior knowledge. This suggested approach, which is flexible to use, makes lessons more interactive.

The findings revealed that concept mapping accompanied with analogies was more enjoyable in assisting students to get interlinks of the related concepts, and reduced their alternative conceptions. Further, such a treatment seems to have resulted in more social collaborations. The current study also showed that context-based chemistry concepts afforded the students to retain newly generated knowledge in their long-term memories, just as Ultay and Calik (2016) found in their use of the REACT strategy. This finding is consistent with those by Aydin, Aydemir and Boz (2009) and Stavy (1991). That is, an increase in familiarity with learning objects and environments promotes constructivist learning.

In light of the results, curriculum developers and textbook authors should focus on a few common misconceptions and handle them within proper conceptual ways. Information and communication technology tools and software could be designed to improve students' representational levels of the 'acid-base' topic. Since these prior knowledge and/or naïve ideas are strong predictors of students' achievement in further chemistry studies, teachers should take students' prior knowledge of acids and bases into account by developing their own lesson plans. Furthermore, because most life reactions contain the acidity or basicity media to facilitate reactions, suitable strategies must be developed by teachers to get students to gain mastery over these concepts.

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Appendix A: **An example of a concept map with some given words**

Weak acid, strong acid, acid strength, weak base, base strength, proton, hydroxide ion, hydrogen ion, acid, base, salt, and named acids and bases

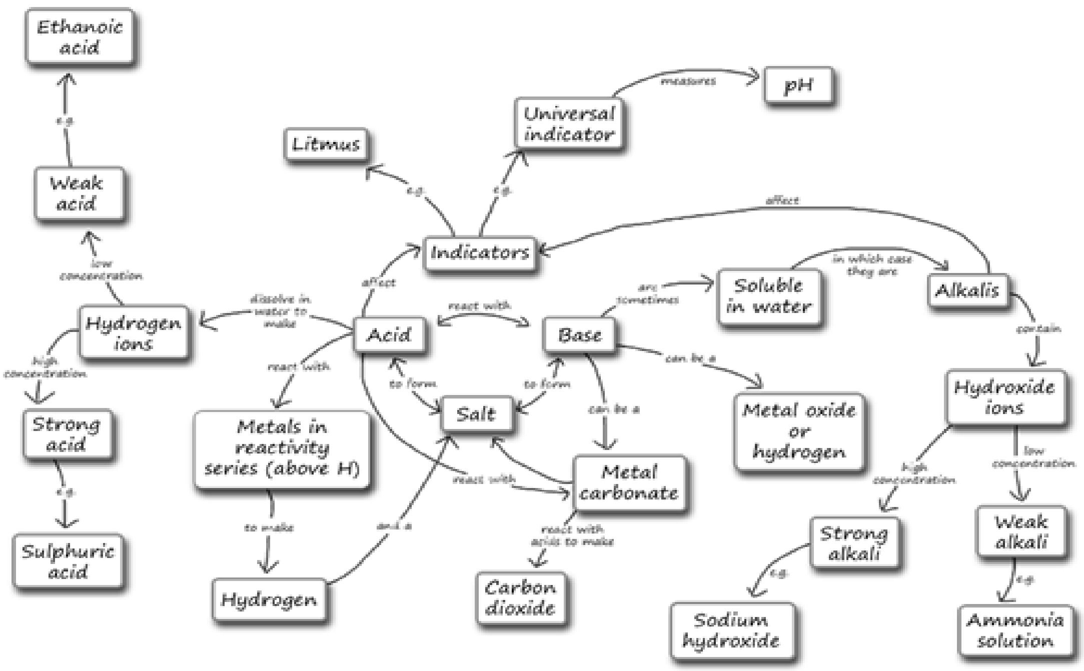

Photo: https:www.google.com.gh/conceptm