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High School Students' Understanding of Acid-Base Concepts: An Ongoing Challenge for Teachers

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Using a quantitative case study design, the *Acids-Bases Chemistry Achievement Test* (*ABCAT*) was developed to evaluate the extent to which students in Malaysian secondary schools achieved the intended curriculum on acid-base concepts. Responses were obtained from 260 Form 5 (Grade 11) students from five schools to initially create the two-tier multiple-choice items. After pilot testing, the final version of the *ABCAT* consisting of 19 items, 10 multiple-choice items and nine two-tier multiple-choice items, was administered to 304 students in Form 4 (Grade 10) from seven secondary schools when 12 alternative conceptions were identified by at least 10% of the students. Of these alternative conceptions, three were displayed by less than 15% of students. The two-tier multiple-choice items had a slightly higher internal consistency reliability (Cronbach's alpha) of 0.54 than the multiple-choices items with a value of 0.42. The data from the study suggest that the *ABCAT* has shown the extent to which the teaching has reduced the incidence of students' scientifically inappropriate understandings; for example, in nine of the 19 items, no alternative conceptions were displayed by the students.

Keywords: acid-base concepts; diagnostic assessments; multiple-choice and two-tier multiple-choice items

INTRODUCTION

The topic on acids and bases has posed many problems to students of various backgrounds. From as early as several decades ago the topic on acids and bases has been reported to be difficult for high school students (Burns, 1982) who have as a result held several alternative conceptions about acids and bases (Artdej et al., 2010;

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Cros et al., 1986; Hand & Treagust, 1991; Nakhleh & Krajick, 1993). Even until recently, several studies have been documented that refer to alternative conceptions about acids and bases that are held by students and teachers alike (Chiu, 2004, 2007; Demircioğlu, Ayas & Demircioğlu, 2005; Huang, 2004; Kala, Yaman & Ayas, 2013; Sheppard, 2006; Drechsler & Van Driel, 2008, 2009). As studies involving students' difficulties in understanding acid-base concepts date back several decades, in this paper we have decided to refer to studies that have identified several alternative conceptions about acids and bases among students and teachers that were conducted during this century. The purpose of this study was to develop a diagnostic test based on the approved chemistry curriculum, referred to as the *Acids-Bases Chemistry Achievement Test* (*ABCAT*), to evaluate the extent to which students in a sample of Malaysian secondary schools had achieved the intended curriculum on acid-base concepts following a regular program of instruction.

THEORETICAL BACKGROUND

According to the constructivist view of learning, what a learner already knows is a major factor that determines the outcomes of learning (Ausubel, 1968). Students develop their views about scientific concepts and phenomena based on their sensory experiences, cultural backgrounds, peers, mass media as well as classroom instruction (Chandrasegaran, Treagust & Mocerino, 2008). There is a tendency for students to be satisfied with their own conceptions because they are often deeply rooted and supported in their daily life experiences (Chandrasegaran, Treagust & Mocerino, 2008). Unfortunately, students' views on science concepts and phenomena could differ from scientifically acceptable conceptions and may cause learning difficulty, especially when the new science concepts are not aligned with their prior experience or conceptual framework. When the new science concepts do not make sense to them, students tend to adhere firmly to their own private views. Consequently, it is beneficial to identify students' understandings about various science concepts so that appropriate instructional strategies may be formulated to challenge and facilitate students' understandings of science concepts (Chandrasegaran, Treagust & Mocerino, 2008).

Understanding of strong and weak acids and alkalis

Several studies have shown that understanding the nature of acids and bases can be confusing. In a study by Chiu (2004), 13% of junior and senior high school students and 34% of senior high school students considered weak electrolytes as consisting of molecules but changed into ions when an electric current was passed through the electrolytes. About 25% of junior high school students also believed that when solutions of equal concentrations of a weak acid like ethanoic acid (CH_3COOH) and a strong alkali like sodium hydroxide ($NaOH$) were mixed, the resulting solution was neutral because the two substances had reacted completely with each other. She also found that 19% of junior and 9% of senior high school students believed that a weak electrolyte exists as molecules in water 'because some molecules decompose to ions, then positive and negative ions attract with each other to combine as molecules again' (p. 435).

With elementary school students in Taiwan, Huang (2004) found that 44% of students assumed that soapsuds were neutral because they were not harmful to human skin or to clothes, while 36% thought that a mixture of a solution of sodium bicarbonate and ethanoic acid was neutral because they produced a neutralisation reaction when mixed together. At the same time, 27% of students assumed that all acids and bases were toxic.

Understanding of pH values

Using the 'interview about events' technique (Osborne & Cosgrove, 1983) in three activities and the 'Predict-Observe-Explain' or POE technique (White & Gunstone, 1992) in a fourth activity Sheppard (2006) investigated the understanding about acid-base concepts among 16 American students who were in grades 10 or 11 (16-17 year-olds). Only four students were able to provide the correct formula for pH as $pH = -\log [H^+]$, while the rest of the students (N = 12) assumed that pH was a linear scale. However, only one of these four students was able to explain the difference between pH 3 and 5 as representing a hundred fold difference in the H^+ ion concentration. At the same time, 14 students assumed that all indicators changed colour at the same pH value of 7. Six students assumed that the process of neutralization involved the physical mixing of an acid and a base while 10 students were aware that a chemical reaction was involved. The products of a neutralization reaction were considered to be acidic by two students and neutral by 13 students.

In the conductimetric titration in activity 4 involving addition of a strong alkali to a fixed volume of strong acid, all the students predicted that the pH would progressively decrease, the reason being alkalis have high pH values and acids have low ones. Only two students predicted an S-shaped curve while eight students suggested a linear representation of the change in pH as acid was progressively added to a fixed volume of alkali. Only one of these two students was able to provide the correct explanation; the other recalled the shape from reading in the textbook but was unable to explain why. After performing the titration, several alternative conceptions emerged in students' explanations. For the first part of the curve that was almost horizontal, seven students suggested that the reaction had not started as yet, while four students believed that no reaction was occurring. Only three students believed that the acid and alkali were actually reacting in the initial part of the titration. The sudden change in pH in the second part of the curve was attributed to reaction suddenly occurring by five students. The correct explanation was provided by only three students who suggested that the acid and alkali were of approximately equal concentrations, so that when more acid was added a large change in $[H^+]$ ion concentration would occur and hence in pH. The levelling of the pH in the third section was attributed by half the number of students to the presence of an excess of acid particles resulting from a mixing of the acid and alkali, not because of any chemical reaction occurring. Only three students explained that there was an increase in the concentration of H^+ ions as a result of the reaction involving the removal of all the OH^- ions. Students' explanations to task 4 contradicted their views about neutralization, pH and chemical change compared to the other tasks probably because they were making spontaneous attempts to explain what to them appeared to be a discrepant event.

Understanding of other acid-base concepts

In another study using POE activities and interviews with 27 high school students, Kala, Yaman and Ayas (2013) investigated their understandings of acids and bases. Some of the students were found to have alternative conceptions about pH and pOH. In one of the POE tasks the students were required to predict the pH and pOH sequence for substances like tap water, lemon juice and HCl. The expected sequence of $pH_{\text{tap water}} < pH_{\text{lemon juice}} < pH_{HCl}$, with the reverse order for pOH was provided by 21 of the students, but only one student gave the correct explanation for the reason for the sequence. At the same time, only four students provided partially correct reasons for the prediction. In conclusion, most students believed that pH was associated with acids and pOH with alkalis.

Demircioğlu, Ayas, & Demircioğlu (2005) used a conceptual conflict instructional strategy to remediate alternative conceptions that were held by 88 grade 10 students (aged 16-17 years) from a high school in Turkey. They used a pretest-posttest control group-experimental group design, with the two groups involving two classes each that were taught by two different teachers. Part of the study involved using a *Concept Achievement Test* (*CAT*) consisting of 20 multiple-choice items on acid-base concepts that was administered before and after instruction. During instruction of the students in the experimental group, the teacher attempted to help the students to recognise and resolve the conflict between their own knowledge and scientific knowledge using worksheets, analogies and practical work. The control group students, on the other hand, were instructed in a traditional manner involving chalk-and-talk and some practical work. There was no significant difference in the pretest mean scores of the two groups indicating that the students in the two groups were equivalent. However, when the mean posttest scores of the two groups were compared after instruction using an independent samples t-test, there was a significant difference in the scores with the students in the experimental group achieving higher mean scores [(experimental group: M = 73.9, SD = 12.7); (control group: M = 60.0, SD = 15.9); t = 4.50, $p < 0.001$]. Before instruction, the percentage of misconceptions held by students in the experimental group ranged from 18% to 84%, while that in the control group it ranged from 20% to 95%. After instruction, this percentage ranged from 0% to 23% for the experimental group and from 2% to 43% for the control group.

Identifying students' conceptions

Multiple-choice items can be used to evaluate students' content knowledge in a topic. However, they are not without limitations. Multiple-choice items often involve a limited number of short answer options without elaboration of the reasons. To address the limitations of multiple-choice items, Tamir (1990) incorporated known alternative conceptions in the responses and required students to provide a reason for selecting a particular response. The provision of justifications to address the limitation of multiple-choice items, proved to be more sensitive and effective in assessing students' learning. This positive outcome led to the development of two-tier multiple-choice items by Treagust (1988, 1995) that enabled the identification of students' alternative conceptions in specific content areas. The first tier is a content question followed by a number of multiple-choice options. The second tier provides a number of alternative justifications for the choice of the answer to the first tier. These short pencil and paper tests are convenient to administer and it does not take long to mark manually. For large samples, specially designed answer sheets can be marked efficiently using optical marking machines that electronically read the answers and summarise the responses in a data file for subsequent analysis.

Treagust (1988, 1995) has provided useful guidelines for the development of instruments containing two-tier multiple-choice items. Figure 1 provides a sample scheme for this development (Treagust & Chandrasegaran, 2007). The development of two-tier multiple-choice diagnostic instruments has been reported in the science education research literature since the 1980s, involving a variety of concepts (Treagust & Chandrasegaran, 2007). One of the earliest two-tier instruments involved the concepts of photosynthesis and respiration in green plants (Haslam & Treagust, 1987). Several other instruments have been developed over the past three decades or so concerning topics and concepts like diffusion and osmosis (Odom and Barrow 1995), chemical equilibrium (Tyson, Treagust & Bucat, 1999), chemical bonding (Tan & Treagust, 1999), multiple representations in chemical reactions (Chandrasegaran, Treagust & Mocerino, 2007), ionisation energies of elements (Tan, Taber, Goh and Chia 2005), electrolysis (Sia, Treagust & Chandrasegaran, 2012) and electrochemistry (Rahayu, Treagust, Chandrasegaran, Kita & Ibnu, 2011), to name a few.

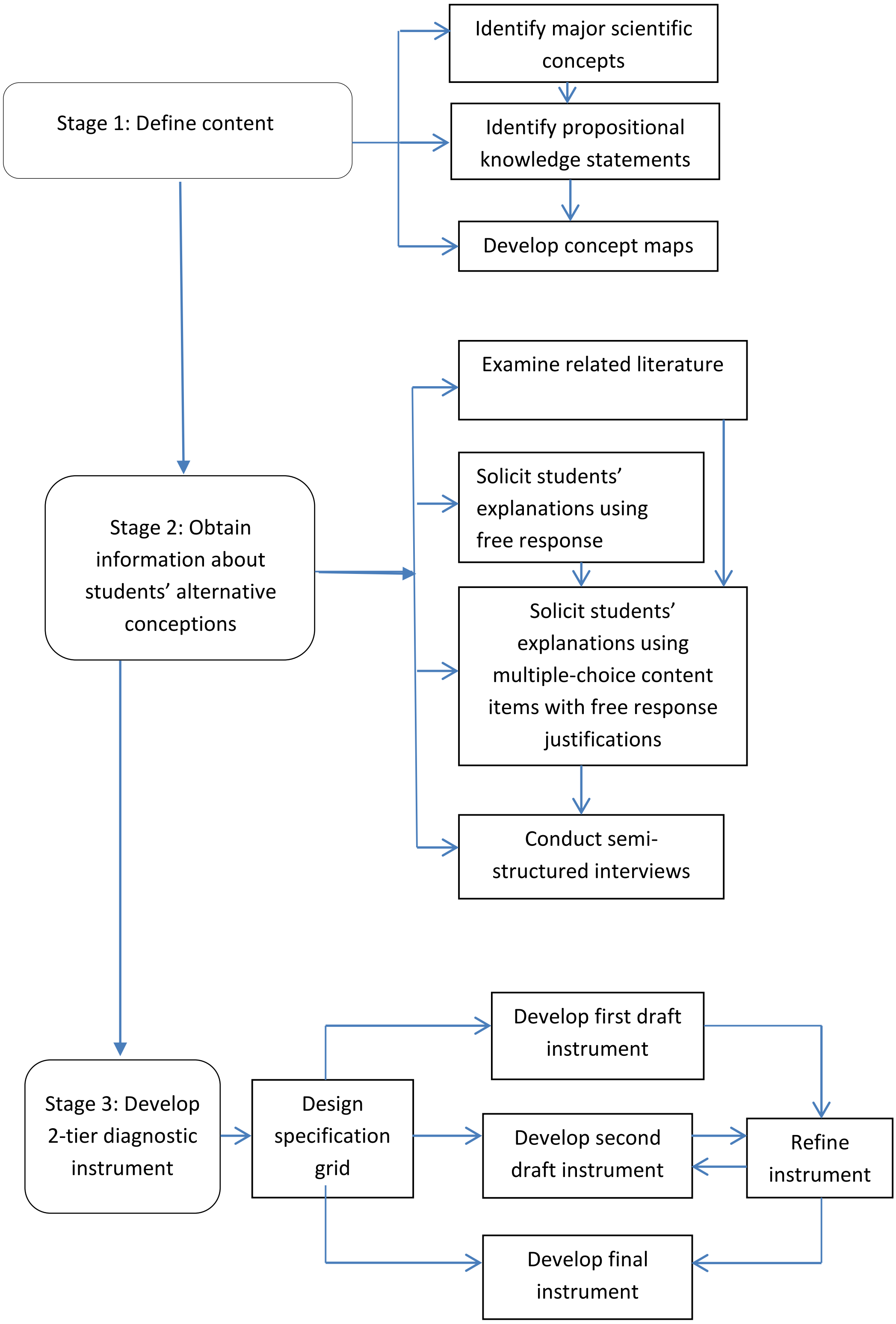

Figure 1. Stages in the development of two-tier multiple-choice diagnostic instruments based on the methodology proposed by Author (1988, 1995)

Although several two-tier items on acids and bases have been previously developed in Taiwan for use in a national study on students' understanding of science concepts (Chiu, 2007), the items were not appropriate for the contents of the Malaysian secondary chemistry syllabus because the chemistry curricula on acids and bases of the two countries were found to be different. For a similar reason, a two-tier instrument used in a Thai study involving grade 11 students (Artdej et al., 2010) was not applicable for this study to evaluate the basic acid-base concepts. Hence, an alternative two-tier multiple-choice instrument on acids and bases, the *Acids-Bases Chemistry Achievement Test (ABCAT)*, was developed for this study.

When ordering statements about what we expect students to learn, we often make use of Bloom's taxonomy of educational objectives (Krathwohl, 2010). These objectives are organised in a hierarchical order that progressively become more demanding. Six major categories have been suggested in Bloom's original taxonomy. These are knowledge, comprehension, application, analysis, synthesis and evaluation. This order of complexity can also be taken into account when developing assessment items.

Rationale for the study

Concepts of acids and bases continue to be a problem for students at all levels of schooling as indicated by several past studies (e.g. Chiu, 2004; Demircioğlu, Ayas, & Demircioğlu, 2005; Huang, 2004: Kala, Yaman & Ayas, 2013; Sheppard, 2006). This study was conducted to evaluate the learning of high school students following a program of regular instruction using an instrument consisting of items that targeted several commonly held alternative conceptions. The absence of some of these alternative conceptions in this study following instruction contributes to the current literature by making available an alternative and efficient diagnostic instrument.

Objectives of the study

The *Acids-Bases Chemistry Achievement Test* (*ABCAT*) was developed in order to assist in evaluating Form 4 (Grade 10) Malaysian secondary students' understanding of acid-base concepts. The *ABCAT* has three major characteristics. First, it is a formative assessment tool, and the results could reflect the students' progress in achieving the intended outcomes of instruction (Bell & Cowie, 2001) on acids and bases. Second, the *ABCAT* is a standardized type of test where students from all the participating schools respond to the same set of test items under similar conditions (Anderson, 2003). Third, the *ABCAT* consists of multiple-choice items that offer a fast and efficient way to analyse large numbers of students' responses (Author, 2006), enabling the teacher to give coherent judgements on their understanding by each student. Consequently, the main research question that guided this study was to determine the extent to which the *ABCAT* could identify the incidence of acid-base alternative conceptions among Grade 10 students following a program of regular instruction.

METHODOLOGY

The study employed a quantitative research design (Cohen, Manion & Morrison, 2011) that involved the development and administration of the *ABCAT.*

Development and administration of the ABCAT

Development of test items

From the Malaysian Forms 4 & 5 (Grades 10 & 11) Chemistry Curriculum Specifications, we have identified a total of 21 out of 26 learning outcomes that describe the Acids and Bases topic, as summarised in Figure 2. These learning outcomes were categorised into four major concepts, namely (1) characteristics and properties of acids and bases, (2) strengths of acids and alkalis, (3) concentration of acids and alkalis, and (4) neutralisation. These learning outcomes were used to develop the items in the *ABCAT.*

Based on the 21 learning outcomes and common alternative conceptions from the research literature, the authors first developed 12 multiple-choice items and 10 two-

Concepts		**Learning Outcomes (LO)** **A student is able to:**
Characteristics and properties of acids and bases.	LO1	State the meaning of acid, base and alkali.
	LO2	State uses of acids, bases, alkalis in daily life.
	LO3	Explain the role of water in the formation of H^+ ions to show the properties of acids.
	LO4	Explain the role of water in the formation of OH^- ions to show the properties of alkalis.
	LO5	Describe chemical properties of acids and alkalis.
The strengths of acids and alkalis.	LO6	Relate pH value with acidic or alkaline properties of a substance.
	LO7	Relate strong or weak acids with degree of dissociation.
	LO8	Relate strong or weak alkalis with degree of dissociation.
	LO9	Conceptualise qualitatively strong and weak acids.
	LO10	Conceptualise qualitatively strong and weak alkalis.
Concentration of acids and alkalis.	LO11	State the meaning of molarity.
	LO12	State the relationship between the number of moles with molarity and volume of a solution.
	LO13	Describe methods for preparing standard solutions.
	LO14	Describe the preparation of a solution with a specific concentration using the dilution method.
	LO15	Relate pH value with molarity of acids and alkalis.
	LO16	Solve numerical problems involving molarity of acids and alkalis.
Neutralisation.	LO17	Explain the application of neutralisation in daily life.
	LO18	Write equations for neutralisation reactions.
	LO19	Describe acid-base titration.
	LO20	Determine the end point of titration during neutralisation.
	LO21	Solve numerical problems involving neutralisation reactions to calculate either concentration or volume of solutions.

Figure 2. Acids and bases learning outcomes identified for this study based on the

Item nos.	**Learning outcomes**	**Item nos.**	**Learning outcomes**
A1	LO3	B1	LO4
A2	LO6	B2	LO5
A3	LO11	B3	LO20
A4	LO15	B4	LO13
A5	LO16	B5	LO7
A6	LO13	B6	LO1
A7	LO14	B7	LO6
A8	LO19	B8	LO2
A9	LO18	B9	LO17
A10	LO21	B10	LO8
A11	LO12		
A12	LO5		

Figure 3. Specification grid relating learning outcomes to items in the final version of the *ABCAT*

tier multiple-choice items. For the development of the two-tier items, the authors initially created the items with the first-tier responses only. Reasons for a particular choice of option, obtained from 260 Form 5 students from five schools, were analysed to develop the second tier of the two-tier multiple-choice items. The content validation of all items involved the match between the items with the specified cognitive learning outcomes from the Malaysian Forms 4 & 5 Chemistry Curriculum Specifications by five experienced chemistry teachers and one chemistry education lecturer. Meanwhile, the bilingual items had been assessed in terms of face validity through back-translation technique (Brislin, 1970).

A specification grid (see Figure 3) was drawn up relating the 22 items in the *ABCAT* to the 21 learning outcomes that were previously identified in Figure 2.

Instrument psychometrics

The difficulty and discriminatory indices for each of the 22 items are summarised in Table 1. Items with difficulty indices in the ranges 0.00 – 0.20, 0.21 – 0.80, and 0.81 – 1.00 are considered difficult, moderate and easy, respectively (Popham, 1995). Based on these criteria, nine of the 12 items in Section A were moderately difficult, while the remaining three items were considered to be easy. As for the items in Section B, eight of the 10 items were moderately difficult while one item was easy and one item was difficult. The wide range in the difficulty indices catered for students with varying abilities (Taylor & Nolan, 2005).

Regarding the discrimination indices, values for items in Section A ranged from 0.00 to 0.50, while the values for Section B ranged from 0.11 to 0.70. According to Authors (2008) items with discrimination indices below 0.2 may not discriminate well between students. Three items, A2, A6 and B3, which had discrimination indices below the threshold value of 0.2 were deleted from the *ABCAT* leaving 10 items in Section A and nine items in Section B.

Table 1. Difficulty and discriminatory indices of the 22 items in the *ABCAT*

Difficulty & discriminatory indices	Section A items (12 items)	Section B item (10 items)
Difficulty index range		
0.11 – 0.20		B3
0.21 – 0.80	A3; A4; A5; A7; A8; A9; A10; A11; A12	B1; B2; B4; B5; B6; B8; B9; B10
0.81 – 1.00	A1; A2; A6	B7
Discrimination index range		
0.00 - 0.20	A2; A6	B3
0.21 – 0.30	A1; A4; A8	B7
0.31 – 0.40	A3; A5; A9; A11	B6; B8
0.41 - 0.50	A7; A10; A12	B10
0.51 – 0.70		B1; B2; B4; B9; B5

The final version of the *ABCAT* containing 19 items (10 multiple-choice items in Section A and nine two-tier items in Section B) had Cronbach's alpha reliability values for Sections A and B of 0.42 and 0.54, respectively. The importance of conceptual tests like the *ABCAT* is attributed to the convenience in administering the test by minimising the time required to complete a limited number of items. In such instances, it would be reasonable to expect a low Cronbach's alpha. On the other hand, a high Cronbach's alpha would not guarantee that the test would be more reliable as it may indicate the presence of redundant items that need to be deleted (Adams & Wieman, 2011). The final version of the *ABCAT* containing 19 items (10 multiple-choice items in Section A and nine two-tier items in Section B) is found in the Appendix.

Research participants

The final version of the *ABCAT* was administered to 304 Form 4 students from seven schools in the district of Melaka Tengah, Melaka in 2011. Students were given 45 minutes to answer the questions.

RESULTS

Comparison of pretest and posttest performances in the ABCAT

The data were analysed to compare students' understandings of acid-base concepts in the pretest and posttest using the *ABCAT*. An independent samples t-test analysis showed that the scores for the posttest were significantly higher than that for the pretest for both sections as well as for the overall instrument (see Table 2).

Table 2. Comparing the *ABCAT* test scores (N = 304)

Section	Pretest		Posttest		t-value	Effect size (Cohen's *d*)
	Mean	SD	Mean	SD		
Section A	3.69	1.82	6.00	1.86	**17.40	0.42
Section B	2.69	1.62	3.94	1.93	**9.72	0.70
Total	6.39	2.83	11.94	3.28	**25.66	1.81

***$p < 0.01$*
(Note: Section A consists of 10 multiple-choice items; Section B consists of nine two-tier multiple-choice items).

The strength of the difference between the pretest and posttest mean scores may be determined by computing the effect size, Cohen's *d*. Cohen (1988) has defined the effect size as being small when $d = 0.2$, medium when $d = 0.5$ and large when $d = 0.8$. The Cohen's *d* values suggest that the difference between the Section A means was average, that between Section B means was close to large while the mean differences between the overall mean scores were very large.

Table 3. Comparison of percentage of students who provided correct responses to each of the items in the *ABCAT* in the pretest and the posttest (N = 304)

Item No.	Correct response	Pretest	Posttest
A1.	A	42.8	87.8
A2.	A	32.9	38.2
A3.	B	31.9	50.3
A4.	B	44.1	71.1
A5.	B	29.3	49.7
A6.	D	17.8	48.4
A7.	B	60.9	80.3
A8.	D	25.7	59.2
A9.	C	41.8	44.7
A10.	C	42.4	70.1
B1.	D2	10.5	33.9
B2.	C2	28.9	46.1
B3.	A3	19.1	37.8
B4.	B1	16.8	42.8
B5.	A3	32.9	48.7
B6.	A1	75.3	88.5
B7.	A3	32.9	30.3
B8.	C1	33.6	40.8
B9.	B1	19.4	25.0

(Note: A1 – A10 are Section A multiple-choice items; B1 – B9 are Section B two-tier multiple-choice items)

The changes in the understandings of acid-base concepts as a result of the instruction are evident for each of the items in the final version of the *ABCAT* in the data provided in Table 3.

There was an improvement in the posttest scores over that of the pretest scores for all items except Item B7.

Alternative conceptions displayed by students

Further analyses were performed to identify the alternative conceptions about acid-base concepts that were still held by the students after instruction. An arbitrary value of at least 10% of students' alternative conceptions was considered in order to ensure that certain alternative conceptions were not excluded. The students were found to display a total of 12 alternative conceptions that are summarised in Table 4.

Table 4. Summary of alternative conceptions about acid-base concepts held by the students (N = 304)

Item no.	Response option	Percentage	Alternative conceptions
A9	A	16.7	When a standard solution of specific concentration is diluted, the concentration of the solution will increase, while the number of moles of solute present will decrease.
A9	B	13.5	When a standard solution of specific concentration is diluted, the concentration of the solution will increase, while the number of moles of solute present will remain constant.
A9	D	25.0	When a standard solution of specific concentration is diluted, the concentration of the solution will decrease, while the number of moles of solute present will also decrease.
A10	B	17.1	Aqueous potassium hydroxide reacts with aqueous sodium chloride to produce a salt and water.
B1	B2	16.8	Sodium hydroxide dissolved in propane ionises to produce OH^- ions.
B2	C1	11.8	A solution with a pH of 3 contains a higher concentration of OH^- ions than H^+ ions.
B3	C3	16.8	A measuring cylinder is the main apparatus that is used in the preparation of a standard solution because it can measure a fixed volume of solution accurately.
B4	A3	27.6	Both sulfuric acid and ethanoic acid are strong acids because they ionise completely in water to produce H^+ ions.
B5	B2	16.8	HCl and CH_4 are both acidic because they contain H atoms in their molecular formulas.
B7	A1	43.8	Soaps and detergents as well as household cleaners contain alkaline chemicals that are able to wash away stains because alkalis are soapy.
B8	C2	11.2	Slightly acidic soil promotes the growth of grass. So, lime is added to change the pH of soil to a value greater than 7.
B9	A2	28.9	Aqueous solutions of potassium hydroxide as well as ammonia are both weak alkalis because they are only partially ionised in water.

DISCUSSION AND CONCLUSIONS

This study has shown that there was a significant difference between the students' overall posttest and pretest mean scores. The difficulties in students' understanding of acid-base concepts is reflected in the 12 general alternative conceptions displayed by the students; however, three of these were displayed by less than 15% of students. Also, in the posttest alternative conceptions were not displayed in the first eight items of the test in Section A (A1 to A8) and in Item B6, supporting the efficacy of the *ABCAT* in identifying the incidence of alternative conceptions among the students. There was generally an improvement in the posttest scores for all except one item. In particular, students displayed limited understanding regarding (1) the properties of alkalis (Item B1), (2) the use of a volumetric flask for preparing a standard solution (Item B3), (3) the function of soaps and detergents as cleaning agents (Item B7), (4) the treating of acidic soils (Item B8), and (5) the difference between strong and weak alkalis (Item B9). Yet, more than 80% of the students were (1) aware that acids ionise in water to produce H^+ ions, (2) aware that the pH of a neutral solution was equal to 7, (3) able to demonstrate the correct sequence in the preparation of a standard solution, (4) able to write the chemical equation for the reaction between an acid and a base, and (5) aware that citrus fruits are acidic with a pH value of less than 7, further supporting the usefulness of the *ABCAT* in identifying the incidence of alternative conceptions. The improvement in the posttest mean scores also indicates effectiveness to some degree of the instruction, similar to the study conducted by Demircioğlu, Ayas, & Demircioğlu (2005) who used a conceptual conflict strategy to remediate students' alternative conceptions. These results suggest that the *ABCAT* has successfully been able to evaluate students' understanding of acid-base concepts; nevertheless, many of these students still held some alternative conceptions about acids and bases. The confusion about the properties of acids and bases that were identified in this study is not surprising as other studies that have been conducted in different cultures as in Taiwan by Chiu (2004) and Huang (2004), in the US by Sheppard (2006) and in Turkey by Kala, Yaman and Ayas (2013) have all indicated related confusion.

In this Malaysian study, students' understanding of acid-base concepts has been evaluated and the reduction of students' alternative conceptions has been identified and reduced following regular instruction that was based on the expected learning outcomes stipulated by the Curriculum Development Division (CDD) of the Malaysian Ministry of Education. The findings show that there is still a need for these Malaysian science teachers to carefully review their classroom instruction to ensure that students are provided with opportunities to develop appropriate understandings of acid-base concepts.

One recommended solution to address this situation would be for the CDD to prepare lists of propositional content knowledge statements for each topic in the syllabus for distribution to schools so that teachers have a thorough understanding of the relevant concepts. Their instruction could then be organised around these propositional content knowledge statements. At the same time, teachers need to be aware of relevant formative assessment procedures and to institute appropriate remedial measures during the course of their instruction. Due to the large number of schools and science teachers in the country, professional development workshops on formative assessment procedures for key personnel could be considered. Using the multiplier effect, these key personnel could then transmit what they have learned to senior science teachers at district level who in turn could conduct workshops for science teachers in their own schools.

The results of this study could be used by chemistry teachers to extend their knowledge regarding students' conceptions about the acids and bases topic. By realizing the existence of particular alternative conceptions, the teachers could plan necessary remedial measures in order to help their students achieve more scientifically appropriate understandings. The results also provide crucial feedback to the Malaysian Ministry of Education (MOE) about the extent to which acids and bases instruction has achieved the intended learning outcomes as specified in the chemistry curriculum. As such, the MOE could organise additional training for teachers which could help them in achieving the intended learning outcomes as well as to deal with students' non-scientific conceptions. By acquiring understanding of basic concepts about acids and bases, students will be better equipped to understand other related areas of chemistry like, for example, in reaction kinetics that often involves comparing the rates of reactions of strong and weak acids (Chairam, Somsook & Coll 2009; Authors, 2010).

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APPENDIX

ACIDS-BASES CHEMISTRY ACHIEVEMENT TEST

Section A

Instruction: Each item in this section consists of four alternative responses A, B, C and D.
For each item, choose one answer only and **circle** your answer in this test booklet.

1. An acid displays its properties when it…..

   A. ionises in water to produce H^+ ions.*

   B. ionises in propane to produce H^+ ions.

   C. ionises in water to produce OH^- ions.

   D. ionises in propane to produce OH^- ions.

2. Which of the following equations correctly describes the relationship between concentration (g dm^{-3}) and molarity (mol dm^{-3})?

   A. $\text{Molarity (mol dm}^{-3}) = \dfrac{\text{Concentration (g dm}^{-3})}{\text{Molar mass (g mol}^{-1})}$ *

   B. $\text{Molarity (mol dm}^{-3}) = \dfrac{\text{Molar mass (g mol}^{-1})}{\text{Concentration (g dm}^{-3})}$

   C. $\text{Concentration (g dm}^{-3}) = \dfrac{\text{Molarity (mol dm}^{-3})}{\text{Molar mass (g mol}^{-1})}$

   D. $\text{Concentration (g dm}^{-3}) = \dfrac{\text{Molar mass (g mol}^{-1})}{\text{Molarity (mol dm}^{-3})}$

3. Which of the following solutions has the lowest pH value?

   A. 20 cm^3 of 2.0 mol dm^{-3} sulfuric acid.

   B. 20 cm^3 of 3.0 mol dm^{-3} sulfuric acid.*

   C. 50 cm^3 of 2.0 mol dm^{-3} sulfuric acid.

   D. 100 cm^3 of 2.0 mol dm^{-3} sulfuric acid.

4. Distilled water is added to 50 cm^3 of 2 mol dm^{-3} potassium hydroxide solution to produce 250 cm^3 of potassium hydroxide solution. What is the concentration of the potassium hydroxide solution produced?

   A. 0.3 mol dm^{-3}.

   B. 0.4 mol dm^{-3}.*

   C. 0.5 mol dm^{-3}.

   D. 0.6 mol dm^{-3}.

5. Which of the following is **not** a step in the procedure to prepare a solution with a specified concentration using the dilution method?

   A. Distilled water is added to the volumetric flask until the graduation mark.

B. A few drops of universal indicator solution are added into the volumetric flask.*

C. The volume of stock solution required is calculated.

D. The required volume of stock solution is transferred into the volumetric flask using a pipette.

6. Which of the following apparatus might **not** be needed for a titration experiment?

A. Pipette.

B. White tile.

C. Retort stand.

D. Test tube.*

7. Which of the following equations most accurately describes the neutralisation reaction between the acid, HA, and magnesium hydroxide?

A. $Mg(OH)_2 + HA \rightarrow MgA_2 + H_2O$

B. $Mg(OH)_2 + 2HA \rightarrow MgA_2 + 2H_2O$*

C. $MgA_2 + H_2O \rightarrow Mg(OH)_2 + HA$

D. $MgA_2 + 2H_2O \rightarrow Mg(OH)_2 + 2HA$

8. A group of chemistry students carried out an experiment in the school laboratory to determine the concentration of a hydrochloric acid solution by titration. In order to do that, they added a few drops of phenolphthalein indicator solution into 25 cm^3 of 1.5 mol dm^{-3} sodium hydroxide solution. The alkali solution was then titrated with the acid solution. The average volume of the hydrochloric acid solution used for this experiment was found to be 28.15 cm^3. What is the concentration of the hydrochloric acid solution used in this experiment?

A. 2.35 mol dm^{-3}.

B. 2.30 mol dm^{-3}.

C. 1.82 mol dm^{-3}.

D. 1.33 mol dm^{-3}.*

9. When a standard solution of specific concentration is diluted, the concentration of the solution will _____, while the number of moles of solute present will be _____.

A. increase; decrease

B. increase; constant

C. decrease; constant*

D. decrease; decrease

10. Aqueous potassium hydroxide reacts with _____ to produce a salt and water.

A. Glacial acetic acid.

B. Aqueous sodium chloride.

C. Dilute nitric acid.*

D. Aqueous magnesium hydroxide.

Section B

Instruction: Each item of this section has two parts, a multiple-choice content response followed by a multiple-choice reason response. For each item, choose your most appropriate response from the first part and **circle** your answer A or B or C, etc. Then choose one of the reasons from the second part that best matches your answer to the first part and **circle** your answer 1 or 2 or 3, etc. If you do **not** agree with any of the given reasons, please write your reason in the space provided.

1. Chemical X shows the following properties:

✓ Tastes bitter and feels soapy.
✓ Turns red litmus paper blue.
✓ Reacts with an acid to produce a salt and water.
✓ Produces ammonia gas when heated with an ammonium salt.
✓ Reacts with an aqueous salt solution to produce a metal hydroxide.

Which of the following is most probably chemical X?

A. Dry ammonia gas.

B. Sodium hydroxide dissolved in propane.

C. Glacial acetic acid.

D. Aqueous calcium hydroxide.*

The reason for my answer is:

1. Chemical X ionises in water to produce H^+ ions.

2. Chemical X ionises in water to produce OH^- ions.*

3. Chemical X ionises to produce OH^- ions in the absence of water.

4. Chemical X is soluble in water.

5. *Other reason:*

____

____

]

2. The table shows the pH values of four aqueous solutions, P, Q, R, and S.

Solution	P	Q	R	S
pH value	13	7	3	9

Which of the following solutions will react with calcium carbonate to produce carbon dioxide gas?

A. P
B. Q
C. R*

D. S

The reason for my answer is:

1. The solution contains a higher concentration of OH^- ions than H^+ ions.
2. The solution contains a higher concentration of H^+ ions than OH^- ions.*
3. The solution contains equal concentrations of H^+ and OH^- ions.
4. *Other reason::*

____

____

3. What is the main apparatus that is used in the preparation of a standard solution?

A. Volumetric flask*

B. Beaker

C. Measuring cylinder

The reason for my answer is:

1. It is easier to dissolve the solute by shaking.
2. It prevents the solution from splashing out.
3. It can measure a fixed volume of solution more accurately.*
4. *Other reason:*

____

____

4. Both sulfuric acid and ethanoic acid are strong acids.

A. True.

B. False.*

The reason for my answer is:

1. Sulfuric acid ionises completely in water to produce H^+ ions, while ethanoic acid ionises partially in water to produce H^+ ions.*
2. Ethanoic acid ionises completely in water to produce H^+ ions, while sulfuric acid ionises partially in water to produce H^+.
3. Both acids ionise completely in water to produce H^+ ions.
4. Both acids ionise partially in water to produce H^+ ions.
5. *Other reason*:

____

____

5. Two common substances that have the formulas HCl and CH_4 both contain the element hydrogen. However, only HCl has acidic properties while CH_4 does **not**.

A. True.*

B. False.

The reason for my answer is:

1. CH_4 completely ionises to produce more H^+ ions in water than HCl.

2. Any substance that contains H atoms in its molecular formula is acidic.

3. Only HCl ionises to produce H^+ ions in water.*

4. *Other reason*:

____

____

6. What is a property of citrus fruits like oranges and lemons?

A. Acidic.*

B. Basic.

C. Neutral .

The reason for my answer is:

1. Citrus fruits have pH value less than 7.*

2. Citrus fruits have pH values greater than 7.

3. Citrus fruits have pH values equal to 7.

4. *Other reason:*

____

____

7. Soaps and detergents as well as household cleaners for floors, ovens and glass windows contain alkaline chemicals like sodium hydroxide and ammonia, but **not** acids.

A. True.*

B. False.

The reason for my answer is:

1. Alkalis are soapy and so are able to wash away stains.

2. Acids are more corrosive than alkalis and so are more effective in removing stains.

3. Alkalis dissolve grease and oils present in dirt more readily than acids.*

4. Acids are able to neutralise alkalis present in dirt.

5. *Other reason:*

____

____

8. If soil is too acidic, it is not likely to support the healthy growth of grass. What chemical would you add to the soil to promote the growth of grass?

    A. Common salt.

    B. Vinegar.

    C. Lime (calcium oxide).*

    D. Caustic soda.

The reason for my answer is:

    1. The basic substance neutralises the acidic soils.*

    2. The basic substance changes the soil acidity to a pH value greater than 7.

    3. The acidic substance changes the pH of soil closer to the ideal pH.

    4. *Other reason:*

    ____

    ____

9. Aqueous solutions of potassium hydroxide as well as ammonia are both weak alkalis.

    A. True.

    B. False.*

The reason for my answer is:

    1. Aqueous potassium hydroxide is completely ionised in water, while aqueous ammonia is only partially ionised.*

    2. Potassium hydroxide and ammonia are only partially ionised in water.

    3. Aqueous ammonia, NH_3, is not an alkali because it does not contain OH^- ions in its formula.

    4. Potassium hydroxide and ammonia ionise completely in water.

    5. *Other reason:*
    ____

    ____

(correct responses are indicated with an asterisk, *)