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# Development of a three-tier test to assess high school students' understanding of acids and bases

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## Abstract

Two-tier tests are such as assessment tools that can make available for teachers/researchers to determine students alternative conceptions and whether a student gives a correct response to a question by understanding the related subject since the second-tier of a test asks for a reason for the first-tier response. The purpose of this study was to develop a valid and reliable three-tier diagnostic test to assess students' understanding of acids-bases concepts. For developing this test, interviews and open-ended questions were administered to high school students and related literature was reviewed; the findings obtained from these steps construct the three-tier test.

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*Keywords:* Chemistry assessment, three-tier tests, acids and bases;

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## 1. Introduction

There are many studies in science education that report students have alternative conceptions and these alternative conceptions affect students' learning and understanding (Anderson, 1986; Palmer, 2001; Ross, & Munby, 1991). Different types of assessments are used in science education in order to identify students' alternative conceptions such as interviews (Boo, 1998; Montfort, Brown, & Findley, 2008; Osborne & Gilbert, 1980; Thompson, & Logue, 2006), open-ended questions (Calik & Ayas, 2005; Chou, 2002; Tsaparlis & Papaphotis, 2002), concept maps (Goh & Chia, 1991), and multiple-choice questions (Schmidt, 1997; Uzuntiryaki & Geban, 2005), which both have advantages and disadvantages in practical usage (Osborne & Gilbert, 1980; Tsai & Chou, 2002). Multiple-choice tests are often more preferable in science classes since they are easy to apply and evaluate students' understanding of the related subject; however, multiple-choice tests have some limitations in applying such as determining whether a student gives a correct response to a test consciously or just by a chance. On the other hand, interviews can give more detailed information about students' alternative conceptions and their understanding on a particular concept, but a large amount of time is needed to conduct interviews with many students for generalizing their alternative conceptions. Because aforementioned techniques have some limitations for practical use in classes, two tier tests are proposed to identify students' alternative conceptions (Treagust, 1986; Treagust, 1995). In order to strengthen the advantages of multiple-choice tests two-tier tests were developed (Tan, Goh, Chia,

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& Treagust, 2002). Two-tier tests are such as assessment tools that can make available for teachers or researchers to determine students alternative conceptions and whether a student gives a correct response to a question by understanding the related subject since the second-tier of a test asks for a reason for the first-tier response. Treagust (1995) also suggests that when diagnostic tests are used either at the beginning or at the end of a topic, an instructor can identify students' alternative conceptions on a related topic and based on students' alternative conceptions the instructor can modify the related lesson plan that remedy students' alternative conceptions. There are some studies on the development of three-tier test in physics (Eryilmaz & Surmeli, 2002; Pesman & Eryilmaz, 2009) and chemistry (Costu, Ayas, Niaz, Unal, & Calik, 2007; Kirbulut, Geban, & Beeth, 2010), in which as an addition to two-tiers the last third tier asks for whether students are sure about their responses to the previous two tiers in the three-tier tests. Therefore, the purpose of this study was to develop of a valid and reliable three-tier diagnostic test to assess students' understanding of acids and bases concepts.

## 2. Method

### 2.1. Sample

The sample of this study was 12th grade high school students in Ankara. Since the study was conducted in the first semester of the 2009-2010 school year, 12th grade students who learnt the acids and bases concepts from the previous semester (when they were 11th grade) were selected as a sample of the study. Three different groups were selected from the target population: i) first group was needed to conduct interviews, 12 high school students (6 female and 6 male) were interviewed; ii) the second group was used to complete open-ended questions, 111 high school students (65 female and 46 male) completed open-ended questions; iii) the three-tier test was administered to the last group, 156 high school students (92 female and 64 male) completed the three-tier test.

### 2.2. Instrument

In order to develop the three-tier acids and bases test, as a first step content boundaries with a list of objectives were determined by four chemistry educators and two chemistry teachers. As a next step, misconceptions were identified by searching related literature, conducting interviews, and administering open-ended questions. First of all, semi-structured interviews with high school students were conducted in order to determine whether there are any misconceptions that do not appear in the literature. The 12 interviewees were selected from 12th grade high school students based on their gender (girls and boys) and knowledge level (high-medium-low) from two different high schools. The interview consisted of 10 questions and their follow-up probes; these questions were adapted from the literature about high school student difficulties in acids and bases concepts in chemistry. The pilot study of the interview questions were administered before the study and the face validity of the questions were tested as well.

Secondly, the interviews results reveal that the high school students had alternative conceptions some reported in the literature and some did not. Therefore, these interview findings and the related literature were used to construct open-ended questions. The open-ended questions were also composed of 10 questions and were conceptual questions covering the acids and bases concepts. In order to check the content validity of questions four chemistry education experts analyzed the open-ended questions in terms of appropriateness to high school students' level, alternative conceptions, and objectives. After administering the open-ended questions to 111 (58.56% girls and 41.44% boys) high school students, students' responses were categorized to form distracters of the three-tier test.

Lastly, the responses of the open-ended questions were analyzed; higher frequencies of categories and meaningful ones were selected as the distracters. These distracters included one correct option and alternative conceptions options. Hence, 18 three-tier questions were constructed; the first tier is the conventional multiple choice step, the second tier is the possible reasons of the given answer for the first tier, and the third tier is the confidence step for the first two tiers. In order to check the content validity of the three-tier test four chemistry education experts and two chemistry teachers analyzed the test in terms of consistencies within first and second tier, appropriateness to high school students' level, alternative conceptions, and objectives. After the revision, the three-tier test was administered to 156 high school students (59% girls and 41% boys) in one class hour.

Table 1. A sample question from an acids and bases diagnostic test

Tiers	A sample three-tier question
First tier	1.1. The chemistry teacher in your class has two beakers and these beakers contain two solutions in the same volume. The teacher tells you that one of the beakers contains, X, a weak acid solution, and the other contains, Y, a strong acid solution. In order to determine which beaker contains <u>the strong acid solution</u> , which of the following information that the teacher gives to you would be <u>merely</u> enough to determine? (a) The concentration of the solutions (b) The pH of the solutions (c) The number of hydrogen atoms in the formulas (d) The dissociation of the solutions (e) The color change rate of litmus paper
Second tier	1.2. Which one of the followings is the reason of your answer for the previous question? (a) As the number of ions in a solution increases, the strength of an acid increases (b) As the dissociation of an acid increases, the strength of an acid increases (c) As the concentration of a solution increases, the strength of an acid increases (d) As the pH of a solution increases, the strength of an acid decreases (e) Strong acids change the color of a solution fast (f) As the number of hydrogen atoms in a molecular formula increases, the strength of an acid increases (g) .....
Third tier	1.3. Are you sure about your answers for the previous two questions; (a) I am sure. (b) I am not sure.

The three-tier acids and bases test covers acids and bases theory, the dissociation of strong acids and bases, the dissociation of weak acids and bases, the reaction of acids and bases, pH, and titrations. A Table 1 shows a sample three-tier question, likewise, each question and reason in the three-tier test had one correct answer and the other options contained alternative conceptions; therefore, high school students' responses were analyzed based on these alternative conceptions.

### 2.3. Data analysis

Four types of variables were used to analyze the data: i) first-tier scores (only the conventional multiple choice step was taken into account), ii) two-tier scores (the first two tiers, the question and the reason of that question, was taken into account), iii) three-tier scores (the all tiers were taken into account), and iv) confidence tiers (only the third confidence tier was taken into account). In addition, the Cronbach alpha reliability was calculated for the first, second and three tier scores.

This categorization was done as indicated by Pesman and Eryilmaz (2009). Based on this categorization students' responses can be analyzed into different level of understanding and patterns: a student's response can give an idea whether that the student responded to the first tier consciously since the second tier sought for its reason and the confidence tier presented whether the student was sure about the responses for the first two tiers, which actually sought for whether the student's errors were because of lack of knowledge or not. If a student answered incorrectly for the first and second tiers and finally sure about the answers for the first two tiers, it could be determined the student has misconception on that particular concept.

## 3. Results

The reliability (Cronbach alpha coefficient) for the first tier scores was found to be .58, for the two-tier scores was .59, and for the three-tier scores was .72. In addition, the relationship between two-tier scores and confidence tiers was investigated by using Pearson product-moment correlation coefficient. The high school students who scored higher in the test were more confident than lower scorers. There was a medium, positive and significant correlation between the two-tier scores and confidence tiers [ $r=.45$ ,  $n=156$ ,  $p<.000$ ], with high scores of two-tiers with high level of confidence (see Figure 1).

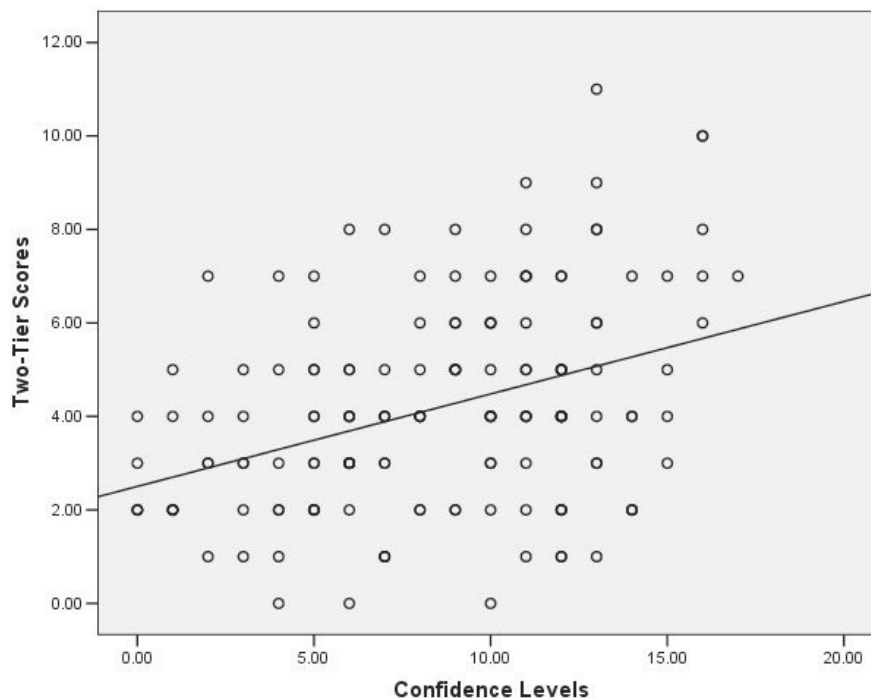


Figure 1. The scattergram of two-tier scores vs. confidence levels

The Figure 1 shows that there are some students scored low with high confidence, which indicates that these students are pretty confident about their responses at the test and probably have misconceptions on acids and bases concepts in chemistry.

#### 4. Implications

In the light of these results, it can be concluded that the developed acids and bases three-tier test provide to be a reliable and valid instrument in order to assess high school students' alternative conceptions and identify their conceptual understanding in acids and bases concepts. Since alternative conceptions are very resistant to change and these they could be problematic for further meaningful understandings on the related concepts, it is crucial to determine them before, during, or after instructions. Three-tier tests are more effective in assessing students understanding rather than conventional multiple choice tests since three-tier tests also differentiate alternative conceptions from lack of knowledge via analyzing the tiers. The Cronbach alpha coefficients for the first-tier, the two-tier, and the three-tier scores were .58, .59, and .72, respectively. The increasing scores of the coefficients from the first-tier to the three-tier could be interpreted that the three-tier test is more reliable than the first-tier and two-tier tests. It is so convenient to use three-tier tests since they are easy and quick to assess students' understanding. In addition, this kind of instruments can be very helpful for instructors even with a large group of students to investigate students' pre-existing knowledge and based on students' background knowledge instructors can design appropriate courses. Therefore, three-tier tests provide instructors information both on students' prior knowledge and also their understandings about concepts after instructions.

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