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Development of a Measurement Instrument to Assess Students' Electrolyte Conceptual Understanding

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To assess students' conceptual understanding levels and diagnosing alternative frameworks of electrolyte, a measurement instrument was developed. Using the measurement instrument, this paper assessed 559 students from grade 10 to grade 12 in two cities, and the arising data were analyzed based on the Rasch model. The results provided both diagnostic and sumative information about students' conceptual understanding, suggesting that measurement instrument had a certain validity. The results also demonstrated that China mainland senior students' understanding grew by grade, and had many alternative frameworks at each level.

Introduction

The research of conceptual learning and assessment has always been the focus of science education. Since the 1980s, the research of alternative frameworks has been the prevalent issue. Researchers found that students always had some ideas that are inconsistent with scientific concepts in conceptual learning. These ideas are labeled as various terms by researchers, for example, misconceptions (Johnstone *et al*., 1977), preconceptions (Ausubel, 1968), alternative frameworks (Driver *et al*., 1978) and students' conceptions (Duit *et al*., 1993). We call them alternative frameworks for consistency in this paper. To diagnose alternative frameworks, researchers have developed many kinds of diagnostic assessment tools. One of the important tools is the paper-pencil test consisting of multiple-choices (McClary, *et al*., 2012; Caleon *et al.*, 2009), such as concept inventory (Mulford, Robinson, 2002; Evans, *et al*., 2003; Krause *et al.*, 2004). Two-tier multiple-choice diagnostic tools are widely used at present (Treagust, 1988; Tan, *et al*., 2002; Chandrasegaran, 2007), which can not only diagnose students' alternative frameworks, but also describe students' understanding by students' reasons. Diagnostic tools are effective in revealing student qualitatively different ways of thinking, i.e., alternative frameworks, they are usually unable to provide summative measures due to their internal consistency and lack of unidimensionality.

Since the 2000s, researchers have had new understandings about students' alternative frameworks. They found that students' alternative frameworks still persist after science learning. Alternative frameworks are changing following conceptual understanding development, and vary at different understanding levels (Aktan, 2013). If the tool is only used to diagnose students' alternative frameworks, but not to measure students' conceptual understanding levels, it just provides limited information about students' state of understanding for a teacher to make decision (Wilson, 2008). Since the middle of 2000s, Rasch measurement, which provides a tool to integrate diagnostic assessment and summative assessment, has been introduced to science education research (Liu, 2012). While this approach is now commonly applied to developing formative assessment with the aim of learning path construction, for example, learning progression (Hadenfeldt, *et al.*, 2013; Claesgens, 2009; Corcoran, 2009). Although some researchers reported instrument that integrated diagnostic and summative assessment (Hoe, Subramaniam, 2015), few researches reported instruments in chemical education integrating diagnostic and summative assessment using Rasch model.

Electrolyte is the key concept in Chinese high school chemistry curriculum, which plays an important role in students' understanding the behaviors of solutions. Assessing electrolyte conceptual understanding is included in the test of assessing solution (Devetak, *et al.*, 2009), acid and base (Mei-Hung, 2007), electrochemistry (Ogude, 1994; Loh, *et al.*, 2014), and chemistry concepts (Davidowitz, 2011; Mulford, 2002). The tools used in these tests were mainly diagnostic. The purpose of this paper is to develop a measurement instrument combining understanding level measurement with alternative framework diagnosing. There are two questions to resolve.

(1) How effective is the measurement instrument when it is used to measure electrolyte conceptual understanding levels and diagnose electrolyte alternative frameworks?

(2) How does students' conceptual understanding of electrolyte change from grade 10 through grade 12?

Method

Developing measurement instrument includes three components: cognition, observation, and interpretation (NRC, 2001). Cognition refers to a theory or construct about how students develop conceptual understanding in a subject domain. Observation refers

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to students' performance based on kinds of assessment tasks and situations. Interpretation refers to a statistical model, which is a summarization of patterns one would expect to see in the data given students understanding levels. Wilson (2008) proposed four building blocks as the steps of developing measurement instruments based on three components. The first building block is progress variables that focus on one characteristic to be measured at a time. The second building block is the item design that refers to a variety of items or tasks used to prompt students' responses. The third building block is the outcome space which students' responses are categorized for all the items associated with the progress variable. The fourth building block is the measurement model, for example, Rasch model. The measurement instrument was developed based on the framework suggested by Treagust (1986) for two-tier instruments and the arising data were analyzed based on the Rasch model by these four steps.

1. Defining the levels of Understanding

The first step was defining understanding levels of electrolyte concept and alternative frameworks. The concept of electrolyte played an important role in understanding behaviors of aqueous solution for senior students. The aqueous solution behaviors included conductivity, acidity and alkalinity, and ionic reaction in previous studies.

For the conductivity of electrolyte solutions, Çalik (2005) surveyed 10th grade students' conceptions about conductivity of electrolyte and non-electrolyte. The results showed 8% students believed electrolyte solutions were not conductive, and students also found it difficult to list some examples of electrolyte. Students had difficulty in connecting electrolyte with other matter categories, such as acid, base and salt. Ogude (1994) examined pre-college and college students' understanding of ionic conductivity in electrolyte solution. The results demonstrated that students always attributed conductivity to the matter of electrons and thought of electrons can freely move in solution when they solved more complex problems of batteries. They suggested that the understanding of the concept of electrolyte should not be isolated from other concepts.

For the ionization of electrolyte, Devetak *et al*. (2009) investigated 16-year-old students' microscopic understanding of aqueous solution. They found 46% students incompletely understood electrolyte ionization, as well as misunderstood ionization and dissolution. The similar case was found in Goodwin's (2002) research, where senior students confused solid melting with dissolution and considered both of them as changing from the solid to liquid. Ogude (1994) found that the pre-college and college students thought of electrolyte as decomposed by current in explaining complex electrochemical phenomena. Nusirjan (1987) found the lower grade senior students thought solid became the mixture of molecules, atoms and ions when dissolved in the water.

For strong electrolyte and weak electrolyte, Chiu (2007) administrated a national survey of acid and base conception understanding in Taiwan. The results revealed 34% senior students thought weak electrolyte were in form of molecular, explaining weak electrolyte was decomposed into ions and ions had opposite electric property recombined of molecules.

For the reaction of electrolyte in solution, Nusirjan (1987) surveyed senior students' understanding about reaction occurring in aqueous solution. The results demonstrated that students of three grades had alternative frameworks for lack of ionic view. Furthermore, students in different grades had obvious differences in their answers when asked to describe products and reaction ions species.

Chinese Chemistry Curriculum Standard of High School (The Ministry of Education of the People's Republic of China, 2003) put forward learning objectives at different stages of electrolyte concept learning. In this paper, we constructed electrolyte conceptual understanding levels by these different stages of learning objectives. Furthermore, students' different alternative frameworks above were divided into different levels, as shown in Table 1.

The electrolyte conceptual understanding levels built as shown in Table 1 is the model of students learning electrolyte concept. This model is the basis for developing measurement tool and the validity should be tested by the results.

2. Designing Items and Scoring Schemes

The second step was designing items and scoring schemes. There were multiple item forms that had different effectiveness to measure understanding levels and diagnose alternative frameworks (Mintzes, *et al.*, 1999). Multiple-choice item was used for measuring understanding levels by Wilson (2008) as a convenient and effective form. Especially, two-tier multiple-choice item, proposed by Treagust *et al*. (2007), was prevalent to diagnose students' alternative frameworks by many researchers (Chandrasegaran *et al.,* 2007; Tan *et al*., 2002; Adadan *et al.*, 2012).

All the items in the measurement instrument were in the form of two-tier multiple-choice. Each two-tier multiple-choice item

Table 1 Students' Electrolyte Conceptual Understanding Levels and Alternative Frameworks

Level 3: Students can describe ionization of weak electrolyte and explain the acid-base properties of solutions by quantitatively mastering the species and changes of particulars.
Alternative framework 1: Weak electrolyte was in forms of molecular in aqueous solution, and ionic with opposite electro property recombined of molecules (Chiu, 2007).
Level 2: Students understand electrolyte ionization based on the interaction between particles in microscopic perspective.
Alternative framework 1: Electrolyte decomposed by current (Ogude, 1996).
Alternative framework 2: Solid became the mixture of molecules, atoms and ions when dissolved in the water (Nusirjan, 1987).
Alternative framework 3: Solid melting is the same as dissolution and they are both from the solid to liquid (Goodwin, 2002).
Alternative framework 4: Ionization and dissolution were the same process (Devetak, 2009).
Level 1: Students distinguish electrolyte and non-electrolyte by the property of solution conductivity.
Alternative framework 1: Electrolyte solutions are not conductive (Muammer, 2005).

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Q5. There are H_2CO_3 solution of 1mol/L and H_2SO_4 solution of 1mol/L. The fact is that the conductivity of H_2CO_3 solution is weaker than solution H_2SO_4, thus it comes the conclusion that H_2CO_3 is weak electrolyte.
A True
B False
Q6. The reason for the answer of Q5 is:
A weak conductivity is not necessarily to weak electrolyte
B H_2CO_3 solution has molecules, molecules are not conductive
C H_2CO_3 is a weak acid, only H^+ is conductive
D H_2CO_3 solution is less O^{2-} than H_2SO_4 solution

Fig. 1 Item Q5/Q6 in Measurement Instrument

Table 2 Items Distribution in Understanding Levels

Understanding levels	Items distribution
Level 3 Explaining problems quantitatively	Q5/Q6; Q13/Q14; Q15/Q16; Q21/Q22; Q29/Q30
Level 2 Understanding particles interactions	Q1/Q2; Q9/Q10; Q19/Q20; Q23/Q24; Q25/Q26; Q27/Q28
Level 1 Recognizing matter category	Q3/Q4; Q7/Q8; Q11/Q12; Q17/Q18

consisted of two questions. The first-tier question aimed at assessing whether students understood the content or not, with the form of dichotomous or multiple choices. The second-tier question mainly diagnosed students' reasons for first-tier answer with the form of multiple choices. Both tiers had only one correct answer. The distracters were designed based on students' possible alternative frameworks, including those listed in Table 1 and others gathering by questionnaire and interview before items designing. The numbers of options are not equal as to each question, and in general two to five options.

The basic criterion for designing items is assuring students can find a reasonable reason in the second-tier corresponding to the answer in the first-tier. Only when correct choices are provided in both tiers does a student answer the item right. If the student selected wrong choice in either tier, he\she was considered to have some alternative frameworks. Student's alternative framework could be diagnosed by combining choices in both tiers. In order to illustrate the process of items designing, we took question 5 and question 6 (abbreviate the item to Q5/Q6) as an example, shown in Figure 1.

The item Q5/Q6 is designed in accordance with understanding level 3. This item mainly assesses whether students master the species of particulars quantitatively according to conductivity experimental fact. While a student chooses A for question 5 and B for question 6 (simply labeled 5A6B), he/she answered correctly in this item. The multiple-choice items had the disadvantage of inflating errors due to guessing if students do not know the correct answer. Take Q5/Q6 as an example. The probability of getting the correct answer through guesswork is 0.125, with 0.5 in the first-tier and 0.25 in the second-tier. If the student chose other answers, it indicated that there maybe exist alternative frameworks. For example, if a student chose 5A6C, we inferred that the student had alternative framework of only hydrogen ions which were conductive by rote. Some options are unreasonable in an item, such as 5B6D. If students selected these options, they are considered not taking the test seriously.

Four to six items were designed for each level. Finally, 15 items, that are 30 questions, are composed to the measurement instrument. The measurement instrument is in Chinese, and it is translated into English（see Appendix 1）. The effectiveness of the tool refers to the Chinese version in this paper. The items distributed in each level were shown in Table 2.

The instrument was tested on contents and corresponding understanding levels by an experienced high school teacher. The items had good content-related validity. Most items were well at its understanding level according to table 2 except item Q13/Q14 and Q17/Q18. The two items were considered to examine some related content of level 2. After balancing the assessing content, the final decision was that the two items were set in the levels in accordance with table 2.

3. Data Collection

The third step was testing senior students in China mainland using measurement instrument. Using the Rasch measurement, there should be variation in students' abilities. A total of 559 students from two high schools located in two cities agreed to participate in this study. We obtained the approval from the two schools for the conduct of this study and did not violate the two schools' ethics law in China. All students participated in this study agreed their responses to the measurement instrument to be used in the analysis. Students' details were given in Table 3.

Students from two cities used different versions of high school chemistry textbooks, and both textbooks were developed based on *Chinese Chemistry Curriculum Standard of High School*. The senior students of grade 10 to 12 were tested in this study. Before administration, the 10^{th} grade students had learned electrolyte concept, including some related concepts of ionization and ionic reaction. Moreover, the 11^{th} grade students had learned weak electrolyte and the 12^{th} grade students learned electrolyte solutions complex behaviors. In common sense, students' understanding would deepen by gradually contents learning. If that was proved by the test, it would give some evidence that the test had well predictive validity (Linacre, 2011).

The whole test was supervised by the school teachers. All students were informed to answer all the questions in the

Table 3 Participants Distribution

Cities	Grade 10	Grade 11	Grade 12	Total
Ji'nan	62	62	57	181
Shi Jiazhuang	129	128	121	378
Total	191	190	178	559

measurement instrument, and most of them could finish the test in 15 minutes. After the test, 559 students' copies of test were collected and mailed to us by teachers.

4. Measurement Model and Data Analysis

The fourth step is using the Rasch model to estimate items difficulties and students abilities in the same scale. The formula and uses of Rasch model can be referred to relevant literature (Liu *et al*., 2006).

Firstly, all the copies collected were numbered by cities and grades. Students' responses were recorded and saved using Excel software as data set. By considering the form of items, each item actually included two questions. Students' answers to each item are given only one code in the form of "title number & option". For example, if a student chose A of question 5 and C of question 6, then it encoded 5A6C. The codes of students' answers were consistent with the alternative frameworks marks of the items. Thus students' alternative frameworks could be diagnosed by the frequency of the options. It is also found that very few students only answered the first tier, the null of second tier were coded 0.

How to infer conceptual understanding levels of students using these raw data? Rasch model is considered as an effective method, which estimates difficulties of items and abilities of students together, and defines the probability of accurate answer as $P=e^{(\theta n-\delta i)}/1+e^{(\theta n-\delta i)}$ with θn being students' abilities and δi being items' difficulties. According to Rasch model, both the underlying understanding levels of students and the difficulty of items can be evaluated. On the one hand, by comparing difficulties of items distributed at different levels, we can test the efficiency of measurement instrument for measuring students' understanding levels. On the other hand, we can also contrast the understanding levels of different grades. In processing the raw data, true score model of classic test theory can hardly assess students' abilities based on various difficulties of items.

There are two basic assumptions using Rasch modeling when analyzing data. One is unidimensionality of measurement instrument, that is, the expected performances of students are based on single latent trait. The other one is local independence of items, that is, the answer of one item is not affected by answers of other items. Two-tier items taken into consideration, the answer of second-tier is bound to that of first-tier. In order to obey the second assumption, the answer of one item is scored one point only in case both tiers are correct answers. Another case is that the answer is scored zero point if either tier is wrong or both tiers are wrong. Therefore, raw data are changed to the dichotomy of 1 and 0, and processed by Winsteps3.72. 0 software.

Results and discussions

1. Validity and Reliability of Measures

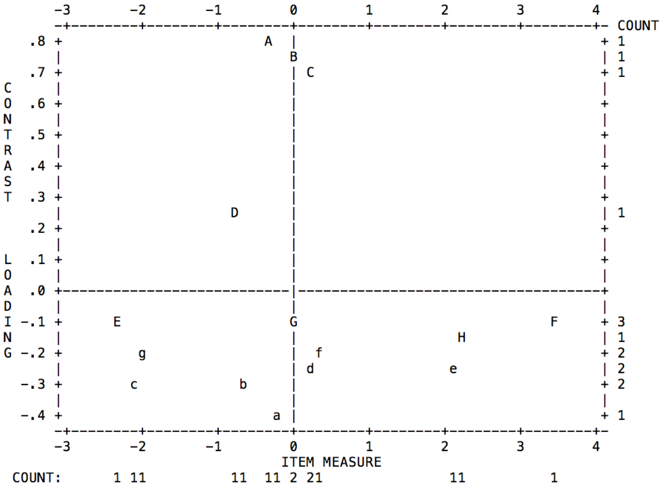

Fig.2 The plot of item loading

Using the Rasch model to estimate understanding levels, the collected data should meet two assumptions, which are unidimensionality and local independence.

Unidimensionality aims at looking for other component not corresponding to the latent trait. The latent trait refers to the "conceptual understanding of electrolyte" in this paper. The unidimensionality was tested by the principal component analysis of residual error.

Figure 2 shows the dimensionality analysis of the measurement instrument in the test. The horizontal axis represents item measures, and vertical axis represents the contrast loading between items and contrast component. The Rasch model explained 38% of total variance, leaving 62% unexplained variance. This shows that the instrument developed was not unidimensional in nature, it is possible that an additional construct could exist. It can be seen that most items had a loading with the -0.4 to +0.4 range; three items (C-Q25/Q26, B-Q1/Q2, A-Q27/Q28) were out of the range. Items with correlation over 0.7 are considered highly locally dependent (Linacre, 2011). Since most of the correlations for the questions are below 0.7, the responses for most of the items developed thus fulfil the criteria for local independence as defined by the Rasch model. Other constructs seem to be underlying the residuals in the light of two items' loading being over 0.7, that are item Q1/Q2 (0.73) and item Q27/Q28 (0.79).

Do these items need to be separated from other items, or to be reconstructed in a new test? Research had demonstrated that the data were difficult to be unidimentional, and whether deleting these items in measurement instrument needed rigorous consideration if these items obviously differed from other items in the light of the measure aim (Linacre, 2011). We examined the items, and found they mainly evaluated the understanding of ionization. Ionization was an essential concept to understand electrolyte aqueous, therefore we decided to keep these items. Items mentioned above require further investigation to improve the unidimensionality of this measurement instrument.

Validity

Does the test measure what it is intended to measure? If the test has measured three levels of electrolyte understanding, then

Table 4 Item Fit Statistics[a]

Item	Measure[a]	Model S.E.	Infit MNSQ	Infit ZSTD	Outfit MNSQ	Outfit ZSTD	PTMEA Corr.
Q1/Q2	-0.02	0.09	0.83	-4.9	0.78	-4.4	0.58
Q3/Q4	-2.02	0.12	1.03	-0.4	1.12	-0.9	0.30
Q5/Q6	2.17	0.14	1.10	1.1	1.52	2.6	0.20
Q7/Q8	-0.82	0.10	0.90	-2.7	0.81	-3.0	0.51
Q9/Q10	-2.29	0.13	1.00	0.1	0.95	-0.3	0.32
Q11/Q12	-2.11	0.12	1.08	1.1	1.16	1.2	0.26
Q13/Q14	-0.02	0.09	1.03	0.8	0.99	-0.1	0.42
Q15/Q16	2.18	0.14	1.25	2.6	1.92	4.3	0.06
Q17/Q18	-0.24	0.09	1.10	2.7	1.12	2.2	0.35
Q19/Q20	-0.70	0.10	1.02	0.60	1.00	0.0	0.41
Q21/Q22	0.31	0.10	1.07	1.8	1.05	0.9	0.38
Q23/Q24	0.27	0.10	1.04	0.9	1.03	0.6	0.40
Q25/Q26	0.19	0.10	0.76	-7.0	0.76	-4.6	0.63
Q27/Q28	-0.32	0.09	0.80	-5.9	0.75	-4.9	0.60
Q29/Q30	3.40	0.21	1.11	0.7	1.76	2.1	0.08

[a]N=559. MNSQ values of 0.70–1.30 indicate the acceptable fit range; Infit (weighted) or Outfit (unweighted) values outside this range indicate poor fit of the data to the Rasch model.

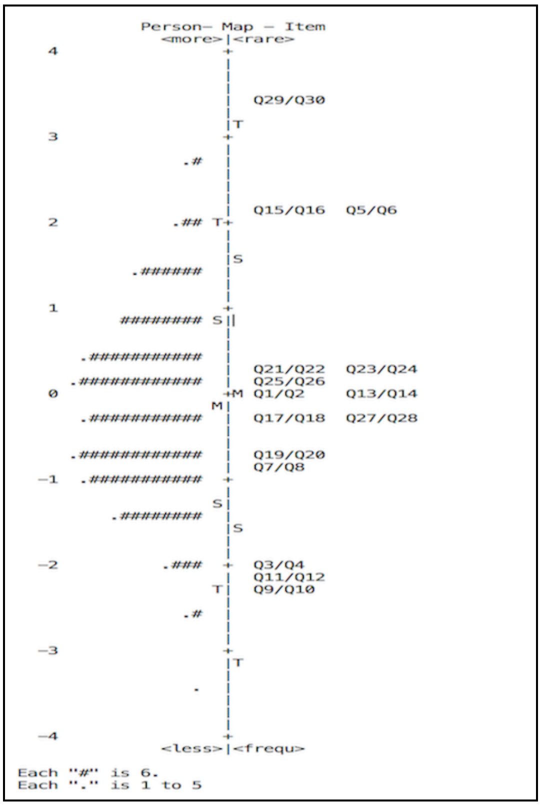

Fig.3 Wright Map

the measurement instrument developed in this paper has construct validity (Linacre, 2011).

The first step is assuring that all items fit Rasch model. The mean square residual (MNSQ) showed how big the impact of the misfit is, with two forms of Outfit MNSQ and Infit MNSQ. Outfit is a chi-square sensitive to outliers in the Rasch analysis. Outliers are often lucky guesses for students of lower ability and careless mistakes for students of higher ability. Infit mean squares are influenced by response patterns, focusing on the responses close to the items' difficulty or students' ability. The expected value of MNSQ is 1.0. PTMEA Corr. value is the correlation between person item scores and person measures. For Rasch analysis, the value should be

Table 5 The Mean Measures of Understanding Levels

Level	Item (measure)	Mean	S.D.
1	Q3/Q4(-2.02); Q7/Q8(-0.82); Q11/Q12(-2.11); Q17/Q18(-0.24).	-1.30	1.30
2	Q1/Q2(-0.02); Q9/Q10(-2.29); Q19/Q20(-0.70); Q23/Q24(0.27); Q25/Q26(0.19); Q27/Q28(-0.32).	-0.48	1.28
3	Q5/Q6(2.17); Q13/Q14(-0.02); Q15/Q16(2.18); Q21/Q22(0.31); Q29/Q30(3.40).	1.61	1.40

Table 6 Summary Statistics of Person and Item

Parameter (*N*)	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	Seperation	Reliability
Persons (559)	0.97	0.0	1.11	0.2	1.18	0.58
Items (15)	1.11	-0.5	1.12	-0.2	12.68	0.99

positive and be not nearly to zero (Bond, *et al.*, 2015). From table 4, all items' PTMEA Corr. Values were positive with a range of 0.06-0.63. Two items' (Q15/Q16, Q29/Q30) values are nearly to zero, so that the two items require further investigation.

The second step is measuring the consistency between items' difficulty and understanding levels constructed in Table 2. That is, the higher the level of conceptual understanding is, the harder the corresponding item is. Wright map is the graphical representation of increased conceptual understanding as show in Figure 3, and the locations of items on the Wright map are derived from empirical analyses of students' data on sets of items.

From the Wright map, it can be seen that all items in the measurement instrument covered most students' abilities. However, three gaps around 2.5 logit, 1 logit and -1.5 logit lack of corresponding items to students' abilities. Items are needed in the further study. There are three counter-cases by comparing different items measures and their corresponding levels. One is that the item Q13/Q14 measure (-0.02) corresponding to level 3 is equal to item Q1/Q2 measure corresponding to level 2. According to the expert validity, the item Q13/Q14 also refers to the content of level 2 and is needed to be revised. The second case is that the item Q17/Q18 measure (-0.24) corresponding to level 1 is higher than some items according to level 2 because "methanol" in item Q17/Q18 are not a familiar matter to students. The last case is that item Q9/Q10 measure (-2.29) corresponding to level 2 is the lowest value because the ionization of magnesium chloride, as a typical example to solution, had been learned by students in junior schools. Overall, 80% items' difficulties are align with the construct.

The third step is calculating mean measures of every understanding level by averaging values of all items at each level. As shown in Table 5, the mean measures from level 1 to level 3 are increasing, which provides more evidence to the validity of the measures.

Reliability

The reliability of measures was established by means of Rasch measurement model as well as classical test theory (Cronbach alpha coefficients). In Rasch analysis, the reliability is a property of person and item measures, with two indicators of person separation index and item separation. The separation index can also be converted to Cronbach's α equivalent value with a range of

0-1. Table 6 showed the summary statistics of the measurement instrument.

It can be seen from Table 6 that personal separation index was 1.18, with an equivalent value of Cronbach's α of 0.58. This person reliability was not very high, but it would not impact teachers' decision to teaching and was suitable for classroom assessment of low- stake. Item separation index was very high, and its corresponding Cronbach's α value was 0.99.

Cronbach's α of classical test theory indicates the consistency within students' responses to all the items in the measurement instrument. The α values for grade 10 students (α_1=0.60), grade 11 students(α_2=0.53) and grade 12 students(α_3=0.66) did not exceed 0.7 which is considered to be an indicator of acceptable reliability. It indicated weak correlations among students' response to the items. It is similar to Luxford *et al.* (2014)' research results in that the reliability did not exceed 0.7 when they tested high school students' understanding of other chemistry concepts. One cause of low value of Cronbach's α was students' fragmented knowledge being measured with alternative frameworks proposed by Adams *et al*. (2011).

2. Students' Conceptual Understanding Levels and Alternative Frameworks

The second question of this paper is how students' conceptual understandings of electrolyte change from grade 10 through grade 12? Using measurement instrument developed in this paper, we assessed students' understanding levels by grade and diagnose their alternative frameworks.

Students' Understanding Levels of Different Grades

In light of mean measures of three levels as listed in table 5, students' ability is divided into different understanding levels. When the students' ability value is lower than -1.30, it is thought that the student conceptual understanding level of electrolyte is below the level 1. When the students' ability is in the range of -1.30~-0.48, it is the level 1. When the students' ability is between -0.48~1.61, it is the level 2. When the students' ability is greater than 1.61, it is the level 3. The students' understanding levels from grade 10 to 12 were listed in table 7.

The mean values of each grade of students' understanding were calculated by averaging students' ability values in each grade. As table 7 showed, the mean values increased by grade from 10 to 12, it indicated that students' conceptual understanding of electrolyte developed by grade and provided some evidence for the predictive validity of measurement instrument. The significant differences of three grade students' understanding were tested by one-way ANOVA. The results reveal there are differences among three grade students understanding [$F(2,556)=5.427$, $p=0.005^{**}$]. Whereby, 10th grade and 11th grade students understanding (N=190, M=-0.21, SD=0.98) have no significant difference (p=0.897), and the similar result appears between 11th grade and 12th grade students (p=0.083). However, there is very significant difference between 10th grade and 12th grade students ($p=0.004^{**}$).

Table 7 Conceptual Understanding Levels of Different Grades

Grade	*N*	Mean (S.D.)	Below Level 1	Level 1	Level 2	Level 3
10	191	-0.33 (1.07)	18.3%	28.8%	48.7%	4.2%
11	190	-0.21 (0.98)	14.2%	55.8%	26.3%	3.7%
12	178	0.04 (1.16)	13.5%	19.7%	60.7%	6.1%

From Table 7, the percentages of students who achieved level 3 in grade 10 to 12 did not get 10%. It suggests that students have difficulty in explaining complicated problems, such as solution conductivity and acid-base properties after learning all the content about electrolyte in high school curriculum. This result is similar to that of Davidowitz *et al.*'s (2011) research. They found that most students still had difficulties in predicting the changes of pH in the light of saline hydrolysis after finishing high school。

About 80% students' understanding were distributed at level 1 and level 2 of each grade. Specifically, the percentage of grade 11 students who got level 1 was far more than grade 10 and 12. However, the percentage of grade 11 students who achieved level 2 was far less than other two grades. This was a probable cause that made no significant difference between grade 11 and other two grades.

Students' Alternative Frameworks of Different Grade

To get more information about students' understanding of electrolyte, students' alternative framework about electrolyte are diagnosed by counting frequency of students choice. Different grades of students' alternative framework are showed in Table 8.

More than 2/3 items had diagnosed students' alternative frameworks as shown in table 8. It suggested the measurement instrument is effective for diagnosing students' alternative framework of electrolyte. Table 8 also showed that students had various alternative frameworks at different understanding levels.

In understanding level 1, the prominent alternative framework is "organics are not electrolytes", with the percentage of 31.4%, 36.1% and 27.9% from grade 10 to 12 respectively. For example, students thought there were no ions in methanol solution because methanol belongs to organics when they answer the Q17/Q18 item. Another dominant alternative framework is "conductive matter is electrolyte" of 28.8% grade 10 students, 24.6% grade 11 students and 21.8% grade 12 students. There was a similar alternative framework that "there are ions in all solution" as well of 29.3% grade 10 students, 22.0% grade 11 students and 24.6% grade 12 students. These alternative frameworks suggested that students made fuzzy relations among the concepts of electrolytes, conductive matter, solution and ions. It was similar to Mummer *et al.* (2005)'s research results in that grade 10 students were unable to distinguish conductive matter, solutions and ions. According to them, students inferred there were ions in all solutions, thus confusing electrolyte solution and nonelectrolyte solution.

In understanding level 2, the dominant alternative framework is that there are no interaction when electrolyte ionization. For example, when students answer the Q29/Q30 item, 61.8% grade 10 students, 64.4% grade 11 students and 65.9% grade 12 students selected the options of "few formic acid molecules automatically ionize" with the reason of "weak electrolyte partially ionization". It indicated that most students couldn't understand electrolyte ionization in the view of particulate interactions. Different from the results by Ogude (1996), few students think of electrolyte as decomposed by current. One important reason is that ionization and current share the same word when translated into Chinese. Teachers

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Table 8 Students' Alternative Frameworks in Different Grade

Understanding levels	Alternative Frameworks	Options	Grade10(%)	Grade11(%)	Grade12(%)
Level 3 Explaining problems quantitatively	a) The conductivity is the same with strong and weak electrolyte when they have the same concentration.	5B6A	62.3	59.7	58.7
	b) A strong acid is not necessarily a strong electrolyte.	13A14B	15.7	15.2	14.0
	c) There is no OH^- in acid solution.	13D14C	27.2	28.8	30.2
	d) There are small amount of ions in water because water is a weak electrolyte.	15D16C	45.0	43.5	50.8
	e) The conductivity of a strong acid is bigger than a weak acid solution.	21A22C	38.7	38.2	38.0
Level 2 Understanding particles interactions	a) Insoluble salts become mixture of molecules and ions.	1B2B	14.1	14.1	—
		27B28B	14.1	21.5	—
		25D26D	26.2	22.5	20.1
	b) Insoluble salts can't ionize.	1C2A	—	12.6	—
		25A26A	—	12.0	—
	c) There are no interactions that occur when an electrolyte ionizes.	15D16D	15.7	13.6	13.4
		29A30B	61.8	64.4	65.9
	d) Electrolyte ionizes after dissolves in the water.	19A20A	16.8	14.1	16.2
Level 1 Recognizing matter category	a) Any electrolyte is a conductor of electricity.	3B4B	—	—	11.7
		23D24A	—	11.0	—
	b) Any conductive matter is an electrolyte.	7A8B	28.8	24.6	21.8
	c) Organic is not electrolyte.	17B18B	31.4	36.1	27.9
	d) There are ions in any solution.	23D24C	29.3	22.0	24.6
		23C24C	13.6	—	10.1

Note: Only the frequency of alternative frameworks over 10% are listed in this table, "—" represents alternative framework less than 10%.

are aware of probable confusion and explain to students that electrolyte ionization is not caused by current. However, the students misunderstand that electrolyte decomposes automatically without interactions among particulates. For example, when answering the Q15/Q16 item, 15.7% grade 10 students, 13.6% grade 11 students and 13.4% grade 12 students thought less water molecules automatic ionization and ignoring the molecules interactions.

Another dominant alternative framework according to understanding level 2 was that students confused ionization and dissolution. When answering Q19/Q20, 16.8% grade 10 students, 14.1% grade 11 students and 16.2% grade 12 students thought calcium chloride ionization occurred after dissolving in water. Devetak *et al*. (2009) also found grade 10 and 11 students couldn't fully understand electrolyte ionization, and mixed them in micro area. When answering Q25/26, 26.2% grade 10 students, 22.5% grade 11 students and 20.1% students thought the insoluble electrolyte were all weak electrolyte, and formed the mixture of ions and molecules after ionization. More than 10% students of grade 11 even thought insoluble electrolyte couldn't ionize. It is in accordance with the results by Nusirjan (1987), they found that students thought insoluble salts became mixture of molecules and ions after ionizing.

In understanding level 3, the 10^{th} to 12^{th} grade of students had difficulties in explaining the conductivity and acid-base property of solutions. When answering the item Q5/Q6, students hardly compared the conductivity of strong electrolyte and weak electrolyte with the same concentration. Students ignored the condition of the same concentration, and intuitively thought weak electrolyte was not necessarily weak conductivity, 62.3%, 59.7% and 58.7% from 10th grade to 12th grade, respectively. The same result was found in the answers of item Q13/Q14. 15.7% grade 10 students, 15.2% grade 11 students and 14.0% grade 12 students thought the strong acid might be weak electrolyte. Some students answered items by literal meaning, for example, 38.7% of 10^{th} grade, 38.2% of 11^{th} grade and 38.0% of 12^{th} grade students thought the conductivity of strong acid was stronger than weak acid solution respectively. Or there was no OH^- in acid solution by rote, 27.2%, 28.8%, 30.2% from 10^{th} to 12^{th} grade, respectively. And they thought there are small amount of ions in water because water is very weak electrolyte, 45.0%, 43.5%, 50.8% from 10^{th} to 12^{th} grade, respectively. It suggested that students made simple relations between strong electrolyte and strong conductivity, acid and hydrogen ions, and so on. It suggested that students lack of systems thinking when they solve aqueous conductivity and acid-base properties quantitatively.

Conclusions

The measurement instrument has a certain construct validity and predictive validity. It can be used both to measure students' understanding levels of electrolyte concept and to diagnose students' alternative frameworks of electrolyte. When the measurement instrument is used to assess students' conceptual understanding of grade 10 to grade 12, it is found that most students were at conceptual understanding level 1 and 2, and very few students got to level 3. At each level of conceptual understanding, students had various dominant alternative frameworks. For example, students made fuzzy connections among the several concepts in level 1, such as electrolyte, conductive matter, solution and ions. Students confused ionization and dissolution at level 2 and had difficulties in explaining the conductivity and acid-base property in level 3. These alternative frameworks are stubborn and do not disappear by the grade.

Developing measurement instrument using Rasch model is an iterating process. In this paper, the results are the first iteration of the test, and demonstrated that few items should be further investigated to improve the unidimensionality and item fit of the measurement instrument. In addition, an abnormal phenomenon is found that the grade 11 students who achieved level 2 are far fewer than grade 10 and grade 12. Further research is needed to provide more evidence for the reason. However, this study is framed as a feasibility one: it is possible to develop a measurement instrument to provide both diagnostic and summative information about students' conceptual understanding.

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Appendix 1: Electrolyte Conceptual Understanding Test

Grade/Class_______________Name _________________NO. ______________.

This test consists of 30 questions totally, and each question has only one correct answer. Please finish all the questions on your own. Some relative definitions in the textbook are provided as following.

Electrolyte: any compound that conducts electricity when melted or dissolved in water

Non-electrolyte: any compound that can't conduct electricity when melted and dissolved in water

Ionization: the process of forming ions when melted or dissolved in water

Strong electrolyte: an electrolyte that completely ionizes in water

Weak electrolyte: an electrolyte that only partially ionizes in water

Q1. Calcium carbonate ($CaCO_3$) is a _____.

A strong electrolyte

B weak electrolyte

C non-electrolyte

Q2. The reason for the answer of Q1 is___.

A the $CaCO_3$ can't dissolve in aqueous solution

B the $CaCO_3$ completely ionizes when melted

C the $CaCO_3$ only partially ionizes in aqueous solution

D the $CaCO_3$ can't ionize in aqueous solution

Q3. The KBr aqueous solution can make the bulb light on. The substance(s) that caused electrical conductivity is (are) ____.

A water

B K^+ and Br^-

C solute

D electron

Q4. The reason for the answer of Q3 is that____.

A water decomposed into hydrogen and oxygen gas by electricity

B KBr is an electrolyte, and all electrolytes conduct electricity

C KBr ionized and freed the ions to move

D KBr decomposed into conductive substances by electricity

E pure water can't conduct electricity unless there are solutes in it

Q5. There are H_2CO_3 solution of 1mol/L and H_2SO_4 solution of 1mol/L. The fact is that the conductivity of H_2CO_3 solution is weaker than solution H_2SO_4, thus it comes the conclusion that H_2CO_3 is weak electrolyte.____.

A True

B False

Q6. The reason for the answer of Q5 is___.

A weak conductivity is not necessary to weak electrolyte

B H_2CO_3 solution has molecules, molecules are not conductive

C $H_2CO_3$is a weak acid, only H^+ is conductive

D H_2CO_3 solution is less O^{2-} than H_2SO_4 solution

Q7. Which matter is a electrolyte in the following?_____.

A NaOH solution

B Cu

C $BaSO_4$

D SO_2

Q8. The reason for the answer of Q7 is____.

A this matter conducts electricity

B there are free moving ions in aqueous solution

C the compound conducts electricity when dissolved in water

D this matter ionized when melted

Q9. What particles exist when magnesium chloride ($MgCl_2$) is heated into the melt state?____.

A Mg^{2+} and Cl^-

B $MgCl_2$ molecules

C water and $MgCl_2$ molecules

D Mg and Cl_2

Q10. The reason for the answer of Q9 is__.

A **$MgCl_2$** completely decomposed into ions

B melting **$MgCl_2$** is a solution

C **$MgCl_2$** does not ionize when melted

D **$MgCl_2$** decomposed into Mg and Cl_2 by electricity

Q11. Hydrofluoric acid (HF) is a weak electrolyte. The concentration of H^+ in 0.1mol/L Hydrofluoric acid solution is_____.

A equal to 0.1mol/L

B greater than 0.1mol/L

C less than 0.1mol/L

Q12. The reason for the answer of Q11 is that ____.

A acid completely ionized into H^+

B water molecules also ionized and produces some H^+

C HF molecules rarely ionized in solution

D not sure how many molecules inozied

Q13. $NaHSO_4$ is a strong electrolyte and the solution is acidic. Which particulate(s) is (are) certainly not in solution?_____.

A SO_4^{2-}

B H^+ and OH^-

C HSO_4^-

D OH^-

Q14. The reason for the answer of Q13 is that____.

A $NaHSO_4$ completely ionized into Na^+, H^+ and SO_4^{2-}

B $NaHSO_4$ completely ionized into Na^+ and HSO_4^-

C there is no OH^- in any acid solution

D neither H^+ nor OH^- exists in salts solution

Q15. Pure water has very weak electrical conductivity. How the rare ions are produced in water?____.

A The interactions are broken in water molecules

B Single water molecule ionized automatically

C By electricity

D Water is a weak electrolyte

Q16. The reason for the answer of Q15 is_____.

A there are interactions among water molecules

B molecules ionized by electricity

C weak electrolyte only partially ionized

D very few water molecules ionized

Q17.Are there ions when methanol (CH3OH) is dissolved in water?_____.

A Yes

B No

Q18. The reason for the answer of Q17 is that___.

A methanol ionized into ions

B methanol is an organic

C there is OH^- in methanol aqueous solution

D methanol is a non-electrolyte

Q19. Calcium chloride（$CaCl_2$） is a compound that consisting of calcium ion and chloride ion. Does calcium chloride ionize when dissolved in the water?_____.

A Yes

B No

Q20. The reason for the answer of Q19 is that_____.

A $CaCl_2$ ionized after dissolved

B the ions are released from the structure by water molecules

C $CaCl_2$ is insoluble

D ionized by electricity

Q21. The electrical conductivity of HCl solution is_____than (as) HClO solution with the same concentration.

A stronger

B weaker

C the same

Q22. The reason for the answer of Q21 is that_____.

A the concentrations of two solutions are the same

B the more ions exist in HCl solution

C the conductivity of strong acid is stronger

D the more ions exist in HClO solution

Q23. In the following matter, which one has free moving chloride ions(Cl^-)?_____.

A KCl crystal

B melted KCl

C KCl aqueous solution

D KCl solution and melted KCl

Q24. The reason for the answer of Q23 is that ___.

A KCl solid consists of K^+ and Cl^-

B the melted KCl is a solution

C all solutions are conductive

D KCl ionized both in solution and in melted state

Q25. What particulates exist in melted silver chloride (AgCl) **? _____.**

A AgCl molecules

B Ag^+ and Cl^-

C AgCl molecules and water molecules

D AgCl molecules, Ag^+ and Cl^-

Q26. The reason for the answer of Q25 is that _____.

A silver chloride didn't dissolve in water

B melted silver chloride is a solution

C silver chloride is a strong electrolyte

D silver chloride is a weak electrolyte

Q27. One aqueous solution contains barium ion (Ba^{2+}), another contains sulfate ion (SO_4^{2-}). When mixing the two solutions together, you will see barium sulphate ($BaSO_4$) precipitated. The $BaSO_4$ is_____.

A a strong electrolyte

B a weak electrolyte

C a non-electrolyte

D neither an electrolyte nor a nonelectrolyte

Q28. The reason for the answer of Q27 is____.

A $BaSO_4$ didn't dissolved in water

B there is no molecules in $BaSO_4$ solution

C there is no Ba^{2+} or SO_4^{2-} in $BaSO_4$ solution

D $BaSO_4$ didn't ionize in aqueous solution

Q29. Formic acid（HCOOH） is a weak electrolyte, and there are few $HCOO^-$ and H^+ in aqueous solution. How the ions are produced?______.

A Few HCOOH molecules ionized automatically

<u>B</u> The interactions in formic acid were broken by water molecule

C There are ions in all electrolyte aqueous solution

D There are H^+ in all acid solutions

Q30. The reason for the answer of Q29 is that_____.

A acid ionized and produced H^+

B a weak electrolyte ionized partially

<u>C</u> the interaction force is different in different molecule