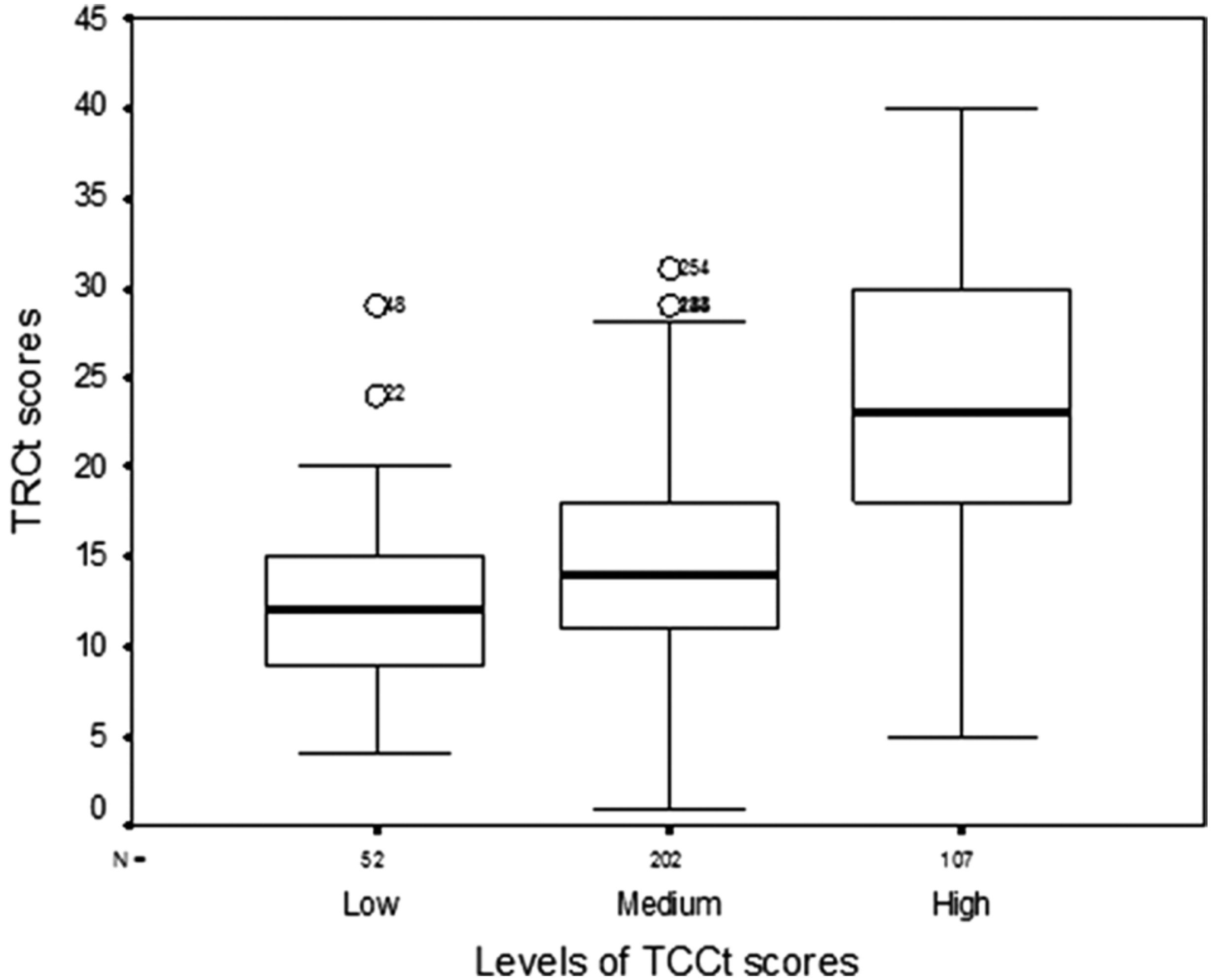


CURRICULUM & TEACHING STUDIES | RESEARCH ARTICLE

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*Cogent Education* (2014), 1: 991180

Sim & Daniel, *Cogent Education* (2014), 1: 991180
**http://dx.doi.org/10.1080/2331186X.2014.991180**

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# Representational competence in chemistry: A comparison between students with different levels of understanding of basic chemical concepts and chemical representations

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Received: 26 March 2014
Accepted: 20 November 2014
Published: 13 December 2014

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Reviewing editor:
Jannette Elwood, Queen's University Belfast, UK

Additional information is available at the end of the article

**Abstract:** Representational competence is defined as "skills in interpreting and using representations". This study attempted to compare students' of high, medium, and low levels of understanding of (1) basic chemical concepts, and (2) chemical representations, in their representational competence. A total of 411 Form 4 science students (mean age = 16 years) from seven urban secondary schools in Malaysia participated in this study. Data were collected from three instruments namely the test of chemical concepts, the test of chemical representations, and the test of representational competence. The Statistical Package for the Social Sciences was used to analyze the data. Findings showed students with a high level of understanding of (1) chemical concepts and (2) chemical representations had significantly higher overall level of representational competence compared to both the medium and the low groups, at $p < 0.001$. However, students with medium and low levels of understanding of (1) chemical concepts and (2) chemical representations showed no significant difference in their overall levels of representational competence. Findings also showed that students' overall level of representational competence had a higher dependence on their level of understanding of chemical concepts than their level of understanding of chemical representations.

## ABOUT THE AUTHORS

Joong Hiong Sim and Esther Daniel are involved in research related to science education, chemistry education, cognition in science education and assessment in science education. While Joong Hiong Sim is also conducting research in medical education, Esther Daniel is actively involved in research in biology education and environmental education. As representational competence is an essential skill to be acquired by every chemistry student, the authors conducted a study to investigate beginning chemistry students' representational competence of basic chemical concepts. The research reported in this paper was part of this larger study.

## PUBLIC INTEREST STATEMENT

This paper focuses on a specific area in chemistry — representational competence in Chemistry, for beginning chemistry students. While the area of study may not be of interest or significance to the general public, the subject of chemistry should draw the attention of most readers. Also known as "The Queen of Sciences", chemistry is the central science. Many concepts in chemistry overlap or inter-relate with concepts in biology and physics and other sciences as well. Due to its abstract nature, chemistry relies on a system of representations. As representations are commonly used in explanations of macroscopic phenomena and as a way of communicating chemical ideas, representational competence becomes a necessary skill in learning chemistry. In this study, representations are discussed at three levels—macroscopic, submicroscopic, and symbolic. Representational competence is defined as "skills in interpreting and using representations".

**Subjects: Science; Social Sciences; Technology; Chemistry; Education**

**Keywords: representational competence in chemistry; chemical concepts; chemical representations; comparison**

## 1. Introduction

In chemistry, phenomena at the macroscopic level such as chemical reactions can be conceptualized in terms of submicroscopic entities such as atoms and molecules, and translated into symbolic representations such as chemical symbols, formulae and equations (Wu, 2003). This multiple levels of representation often make chemistry a difficult subject, particularly for beginning chemistry students (Gabel, 1999; Johnstone, 1991).

As representations are commonly used in explanations of macroscopic phenomena and as a way of communicating chemical ideas, representational competence becomes a necessary skill in learning chemistry (Treagust, Chittleborough, & Mamiala, 2003). However, numerous studies have shown that learners at all levels of chemistry have difficulties in interpreting and using representations of chemical concepts (Gabel, 1999; Heitzman & Krajcik, 2005; Kozma & Russell, 1997; Wu, Krajcik, & Soloway, 2001). This is because representation of chemical concepts requires the learners not only to understand the chemical concepts and chemical representations involved, but also the ability to translate between representations. According to Kozma (2000), all these difficulties indicate a lack of links among chemical phenomena (macroscopic), representations (symbolic), and relevant concepts (submicroscopic). Translating chemical representations involves thinking about phenomenon in three different levels of representation—macroscopic, symbolic and submicroscopic, that are directly related to each other (Gabel, 1999; Johnstone, 1982, 1991, 1997, 2006). However, making translations between representations is an information-processing task that requires knowledge and understanding of the underlying concepts (Keig & Rubba, 1993). Students' conceptual errors and difficulties understanding and using representations in chemistry (Heitzman & Krajcik, 2005; Keig & Rubba, 1993; Kozma & Russell, 1997; Wu & Shah, 2004) further suggest that chemical representations are not just visual diagrams but are conceptual constructs as well (Hoffmann & Laszlo, 1991). Wu et al. (2001) believed that visualizing chemical representations require the cognitive linkages between conceptual components that involve substantial content knowledge of underlying concepts, and visual components that involve encoding and interpreting the representations. Many novice learners are unable to create a link between the three levels of thinking simultaneously. This may result in rote learning to acquire fragments of unrelated information. In the absence of linkages, knowledge is compartmentalized in the long-term memory.

However, representational competence cannot be studied out of context. Since the research question is Form 4 students' representational competence of basic chemical concepts, therefore students' overall levels of understanding of basic chemical concepts and chemical representations also need to be assessed.

### *1.1. The study and its rationale*

Although chemical education research is flooded with literature on representational competence (Chittleborough & Treagust, 2007; Davidowitz, Chittleborough & Murray, 2010; Kozma & Russell, 1997, 2005; Nitz, Nerdel, & Prechtl, 2012; Parnafes, 2010; Parnafas, Aderet-German, & Ward, 2012; Stieff, 2011; Stieff & McCombs, 2006; Wu & Shah, 2004), the participants in most of these studies were college students, undergraduates, and even postgraduates and expert chemists. Findings of these studies cannot be generalized to Form 4 science students. Not only is representational competence domain-specific, representational competence may also vary across age or educational levels, as well as between experts and novices (Chi, Feltovich, & Glaser, 1981; Kozma & Russell, 1997).

While it is well accepted that skills in interpreting and using chemical representations is vital for success in chemistry, a review of literature shows hardly any research has been conducted on or related to students' representational competence in chemistry at any level in Malaysia. Thus far, a wide literature search conducted by the researcher also did not uncover any study comparing learners with different levels of understanding of chemical concepts and chemical representations in their representational competence in chemistry on novice chemistry students. It is important for chemistry students to be competent in interpreting and using chemical representations to learn chemistry. If students encounter difficulties at one of the three levels of representations (macroscopic, submicroscopic, or symbolic), or have confusion between the three levels, it may interfere with further learning in chemistry. The right time to begin acquiring some skills in using representations is at an early stage in their study of chemistry. Therefore, a study to investigate Malaysian Form 4 science students' representational competence in chemistry, and an attempt to compare learners with different levels of understanding of chemical concepts and chemical representations in their representational competence, is both timely and appropriate.

### *1.2. Objectives of the study*

The general purpose of this study was to investigate Malaysian Form 4 science students' representational competence of basic chemical concepts. The two objectives were to compare students' of high, medium, and low levels of understanding of (1) basic chemical concepts, and (2) chemical representations and their overall levels of representational competence in chemistry.

## 2. Method

This section describes the method and procedures of the study. This includes: the sample, the instrument, data collection, and data analysis.

### *2.1. The sample*

Through stratified sampling, a representative sample was obtained for the study. The sample comprised 411 Form 4 science students from seven urban secondary schools in Malaysia (Tables 1 and 2). Of the seven schools selected, three were National Type Secondary Schools, three were National Secondary School, and one was a Technical Secondary School. In terms of gender composition, four were co-educational schools, two were all-boys schools and one from an all-girls school. Tables 1 and 2 show the profile of the participants in terms of gender and ethnic background, respectively. Since the target population was urban students, majority of the students in the sample (74.2%) were of Chinese origin (Table 2).

At the time of data collection, the age of the participants ranged from 15 to 17, with a mean age of 16 years. All the participants were taking chemistry as a subject for the first time. Other similar key characteristics included: (1) same chemistry curriculum, (2) same assessment instruments, (3) same medium of instruction (English), and (4) same chemistry textbook.

**Table 1. Profile of the participants in terms of gender**

| School* | Gender | | Total |
|---|---|---|---|
| | Male | Female | |
| YC | 98 | 44 | 142 |
| NH | 53 | 62 | 115 |
| SP | 21 | – | 21 |
| DMK | 10 | 21 | 31 |
| TK | 7 | 16 | 23 |
| TC | – | 37 | 37 |
| ST | 42 | – | 42 |
| Total | 231 (56.2%) | 180 (43.8%) | 411 (100.0%) |

*Abbreviations are used for confidentiality.

**Table 2. Profile of the participants in terms of ethnic background**

| School* | Race | | | Total |
|---|---|---|---|---|
| | Chinese | Malay | Indian | |
| YC | 139 | 1 | 2 | 142 |
| NH | 112 | 3 | – | 115 |
| SP | 9 | 8 | 4 | 21 |
| DMK | – | 25 | 6 | 31 |
| TK | – | 22 | 1 | 23 |
| TC | 4 | 16 | 17 | 37 |
| ST | 41 | 1 | – | 42 |
| Total | 305 (74.2%) | 76 (18.5%) | 30 (7.3%) | 411 (100.0%) |

*Abbreviations are used for confidentiality.

### *2.2. The instruments*

Data for the study were obtained from three instruments namely the test of chemical concepts (TCC), test of chemical representations (TCR), and test of representational competence (TRC). Sample questions for the TCC, TCR, and TRC are given in Appendix A.

#### *2.2.1. Test of chemical concept*

This is a two-part paper-and-pencil test used to assess students' understanding of basic chemical concepts. Basic chemical concepts related to matter were assessed. These included pure substances and mixtures, elements and compounds, atoms, molecules and ions, sub-atomic particles, atomic number and nucleon number, electron arrangement, valence electron, and the idea of a physical change or a chemical change, and chemical bonds. Items in the TCC were generated by the researcher based on classroom experience. After the content area of interest had been determined, a table of specification was constructed to establish content validity of the instrument. To check for face validity and content-related validity, the initial draft was given to two experienced chemistry teachers and a professor of chemical education for validation. The items in the TCC appeared to be relevant for testing students' understanding of basic chemical concepts. Their feedback was used to fine tune the structure of the TCC. The instrument was then field-tested to estimate the time required for the subjects to complete the test, find out the difficulty level, as well as the discriminating power of each item. Item analysis was done by computing the difficulty index ($p$ value) and the index of discrimination (ID) for each item. Items with an undesirable difficulty index or ID were either reconstructed or discarded. Such fine-tuning procedures were necessary to increase the reliability of the new instrument. The final version of the TCC contained 15 true–false items in Part A and another 15 multiple-choice questions in Part B. For both Parts A and B, each correct answer was awarded one point. Hence, total possible test point for the 30 dichotomous items was 30. To further enhance content validity, the reconstructed TCC was submitted for validation to the same panel of reviewers. Their feedback was favorable. As each item in the TCC was scored dichotomously, test score reliability was estimated using the Kuder–Richardson formula (Mehrens & Lehmann, 1973). A KR-20 of 0.59 was recorded for the 30-item TCC. Test–retest with a smaller sample ($n$ = 45) after a three-week interval gave a correlation coefficient of $r = 0.84$.

#### *2.2.2. Test of chemical representations*

This is another two-part paper-and-pencil test used to assess Form 4 students' understanding of chemical representations. The content domain of interest was the three levels of chemical representation of matter (macroscopic, submicroscopic, and symbolic). This content domain was determined after careful examination of some curriculum and instructional materials such as the Curriculum Specifications for Form 4 Chemistry (Malaysian Syllabus), as well as the text book and reference books currently used by Form 4 science students in Malaysia. A review of literature related to chemical education research was conducted to prepare the draft version of the TCR. Various curriculum and instructional materials related to chemistry were critically examined. A collection of students' incorrect answers in their written exercises, test papers, and examination scripts were also rich resources for constructing the items. Each item consisted of a propositional statement related to the three levels of representation of matter. Content validity of the instrument was also established by: (1) constructing a concept map of the three levels of chemical representation of matter, (2) determining the content domain of the test, and (3) preparing a table of specification for the test. To investigate students' understanding through the "true" or "false" item format, a useful strategy is to create pairs of statements, one true and one false, based on a single idea. For example: (1) $H_2$ and $O_2$ are symbols of the elements hydrogen and oxygen, respectively, and (2) H and O are symbols of the elements hydrogen and oxygen, respectively. While statement (2) is a true statement, statement (1) is a false statement. In this item format, the intended correct answer should be obvious only to those who have good command of the concept being tested, whereas the wrong answer would be attractive to those who lack the desired command. To enhance item discrimination, several other measures have also been taken which included using more false statements than true statements. It is believed that when in doubt, students seemed more inclined to accept than to challenge propositions presented in a true–false test. False statements also tend to be more highly discriminating than true statements (Ebel, 1993). Another option would be to word the item so that superficial logic suggests a wrong answer or to make the wrong answer consistent with a popular misconception. A total of 25 true statements and 37 false statements were tentatively generated. These statements were then carefully examined to make sure that each of the statements was clearly true or clearly false. A final selection of statements to be included in the TCR was made. The number of true statement and false statement was trimmed down to 20 and 30, respectively, giving a total of 50 statements. Subsequently, the 50 statements were randomly placed to form the 50-item TCR. To check for face validity and content-related validity, the draft version of the TCR was reviewed by the same panel of reviewers as the TCC. The items in the TCR appeared to be relevant for the purpose of this study. The TCR was then pilot-tested to estimate the time required for the subjects to complete the 50-item test, to estimate the difficulty level and the ID of each item, and to serve as a trial run. Difficulty index (p) and ID for each item were computed. For a test, normally items with undesirable $p$ value or ID are either reconstructed or discarded. However, a check of ID showed that most of the items with low ID (<0.20) were items with low (between 0.10 and 0.30) to very low (<0.10) $p$ values. These appeared to be difficult items which even the good students could not answer. Although deleting these items would increase reliability of the test score, it defeated the purpose of administering the test. Hence, these items were retained. Feedback from the pilot study was used to reconstruct the final version of the TCR for the actual study. The TCR used for the actual study contained 30 true–false items in Part A and six multiple-choice items in Part B. With 30 of the 36 items in the true–false format, test–retest reliability was considered to be more appropriate to check on test score reliability. For the pilot study, test–retest with a smaller, random sample ($n$ = 33) after a three-week interval gave a correlation coefficient of $r$ = 0.82. In the actual study, test–retest with a random sample ($n$ = 45) after a one-month lapse gave a correlation coefficient of 0.64. These figures suggested that the scores on the TCR were relatively stable over time.

### *2.2.3. Test of representational competence*

For the purpose of investigating students' representational competence in chemistry, a further paper-and-pencil test—the TRC was administered. The test was divided into two parts, with 25 multiple-choice items in Part A, and seven short response format items in Part B.

*2.2.3.1. Development of the TRC.* Although in practice, representational competence covers a wide range of skills and practices, the samples in this study were novices to chemistry. Hence, only five representational skills were assessed. These skills were: (1) the ability to interpret meanings of chemical representations, (2) the ability to translate between different representations at the same level, (3) the ability to translate between different representations across levels, (4) the ability to use representations to generate explanations, and (5) the ability to make connections between representations and concepts. A survey of literature, curriculum and instructional materials, past-year examination papers (past-year papers for both the Australian National Chemistry Quiz, the

Malaysian National Chemistry Quiz), and online search were carried out in order to prepare the pilot version of the TRC. Relevant questions selected from various sources were modified appropriately where necessary while some items were generated by the researcher. The pilot version comprised a total of 32 questions in two parts. Part A contained 25 multiple-choice items, while Part B contained seven short answer format items with 15 parts. For Part A, each correct answer was awarded one point; thus, the total possible test point awarded for the 25 dichotomous items was 25. For Part B, one point was awarded for each part of the correct answer. The total possible test points awarded was 15. Hence, test score for the TRC (TRCt score) could range from a minimum of 0 to a maximum of 40 points. The instrument was pilot-tested. Item analysis was done by computing the difficulty index ($p$ value) and the ID for each item. The difficulty indices of the items, which ranged from 0.10 to 0.93, provided a wide range of difficulty in the items. About 15 of the 25 multiple-choice items were moderately difficult, with $p$ values ranging from 0.30 to 0.70. Besides, the indices of discrimination of the items ranged from 0.31 to 0.94 for 20 of the 25 items, with 18 of the items having ID > 0.40. Items with undesirable difficulty index or discrimination index were either reconstructed or discarded to increase the reliability of the new instrument.

*2.2.3.2. Validity of the TRC.* Since the TRC was also a new instrument, its validity for this study needs to be established. To establish the content validity, the representational skills assessed were predetermined and a table of specification was prepared. To check for face validity and content-related validity, the initial draft of the TRC was given for validation to the same panel of reviewers as the TCC and the TCR. Their feedback was used to fine tune the structure of the TRC.

*2.2.3.3. Reliability of the TRC.* As each item in the TRC was scored dichotomously, test score reliability was estimated using the Kuder–Richardson formula (Mehrens & Lehmann, 1973). Pilot study of the TRC with a similar sample of students ($n$ = 60) gave a KR-20 of 0.96 for the 25 multiple-choice items in Part A. KR-20 was computed instead of KR-21 as the difficulty levels of the items were different. All items in the instrument were marked by the researcher herself. However, to ensure reliability of marking, 25% of the scripts ($n$ = 15) were randomly selected from the total scripts and were given to two experienced chemistry teachers for cross-validation. As a check on the level of agreement between raters of the TRC scores across the seven items in Part B of the TRC, Cohen's $\kappa$, an index of inter-rater reliability that corrects for chance agreement between raters, was computed. For the pilot study, the k values obtained were 0.845 (rater 1 × rater 2), 0.769 (rater 1 × rater 3), and 0.920 (rater 2 × rater 3). These k values indicate a high level of agreement between the raters. The average k value is 0.845. Further discussions with rater 2 and rater 3 were subsequently held to refine the scoring procedures. A final version of the marking scheme was also ascertained. In the actual study ($n$ = 384), values of KR-20 of 0.81 and 0.87 were recorded for the 25 multiple-choice items in Part A and the seven short answer items in Part B, respectively. KR-20 for all the 40 items of the TRC was also computed. A value of 0.90 was recorded. These KR-20 values indicated that the new instrument has very high reliability. Additionally, Cohen's $\kappa$ was computed for the seven items in Part B. To ensure reliability of marking, 25% of the scripts ($n$ = 96) were randomly selected from the total scripts and were given to two experienced chemistry teachers for cross-validation. The k values obtained were 0.795 (rater 1 × rater 2), 0.807 (rater 1 × rater 3), and 0.989 (rater 2 × rater 3). The average k value is 0.864. These k values indicate a high level of agreement between the raters. To further ensure consistency in the marking, the inter-raters in the pilot study and the actual study were the same. While rater 1 was the researcher, raters 2 and 3 were reviewers of the TRC.

### *2.3. Data collection*

Data collection was carried out over a period of two to three weeks. At the time of data collection, the participants were in the second semester of their Form 4 Chemistry course, and they had been taught all the basic chemical concepts and exposed to chemical representations assessed in this study. All the three instruments were administered by the researcher herself.

Table 3 shows the actual sample sizes, test time, and the session number for each of the test.

**Table 3. Administration of the tests**

| Test | Sample size ($n$) | Time (min) | Session number |
|---|---|---|---|
| Test on representational competence (TRC) | 384 | 60 | 1 |
| Test on chemical concepts (TCC) | 383 | 30 | 2 |
| Test on chemical representations (TCR) | 379 | 30 | 2 |
| Any one instrument | 411 | – | – |

### *2.4. Data analysis*

Data were processed using the Statistical Packages for the Social Sciences, Statistical Package for the Social Sciences. An alpha level of 0.05 was used for all the statistical tests.

A student's overall level of understanding of basic chemical concepts and chemical representations was indicated by the TCCt score and TCRt score, respectively, while his/her overall levels of representational competence were based on the TRCt score.

To test whether there are significant differences in the representational competence among the three groups with different levels of understanding of (a) chemical concepts, and (b) chemical representations, one-way analysis of variance (ANOVA) was performed. Normality of data was assessed using the normal probability plot, which compares the cumulative distribution of actual data values with the cumulative distribution of a normal distribution. The normal distribution forms a straight diagonal line and the plotted data values are compared with the diagonal.

## 3. Results

Basic descriptive statistics for students' overall levels of understanding of: (1) basic chemical concepts, (2) chemical representations, and (3) their representational competence in chemistry are summarized in Table 4.

Mean scores for the TCCt, TCRt, and TRCt were 13.68 (45.60%), 18.63 (51.75%), and 16.90 (42.25%), respectively.

### *3.1. Comparing students of different levels of understanding of chemical concepts in their representational competence*

Although the number of students taking the TCC and TRC were 383 and 384, respectively, only those students who took both the tests ($n$ = 361) are included in this comparison.

For the purpose of comparison, the students have been categorized into three levels of understanding of chemical concepts based on their TCCt scores. Ranges for the low (L), the medium (M), and the high (H) groups are based on quartiles of their TCCt scores. Sample size for the [1]low, the [2]medium and the [3]high groups are $n$ = 52, 202, and 107, respectively.

A comparison of students of different levels of understanding of chemical concepts in their representational competence is summarized in Table 5.

**Table 4. Mean, standard deviation, minimum, and maximum of test scores**

| Test scores | $n$ | Maximum score possible | Mean (%) | SD | Minimum (%) | Maximum (%) |
|---|---|---|---|---|---|---|
| TCCt | 383 | 30 | 13.68 (45.60) | 3.904 | 5 (16.67) | 25 (83.33) |
| TCRt | 379 | 36 | 18.63 (51.75) | 3.274 | 7 (19.44) | 27 (75.00) |
| TRCt | 384 | 40 | 16.90 (42.25) | 7.781 | 1 (2.50) | 40 (100.00) |

**Table 5. A comparison of students of different levels of understanding of basic chemical concepts in their representational competence**

| Levels of TCCt score | *n* | TRCt score | | | |
|---|---|---|---|---|---|
| | | Mean | SD | Minimum | Maximum |
| Low | 52 | 12.38 | 4.598 | 4 | 29 |
| Medium | 202 | 14.46 | 5.813 | 1 | 31 |
| High | 107 | 23.74 | 7.870 | 5 | 40 |
| Total | 361 | 16.91 | 7.764 | 1 | 40 |

Graphically, the representational competence of the subjects ($n$ = 361) with different levels of understanding of chemical concepts can be compared using box plots, as shown in Figure 1.

Normal probability plots of TCCt scores and TRCt scores are shown in Figure 2. Visual examination of the normal probability plots shows little or no violation of normality of data as the line representing the actual data distribution closely follows the diagonal. Hence, ANOVA could be performed. Table 6 presents the results of the one-way ANOVA.

**Figure 1. Box plots of TRCt scores for three levels of TCCt scores.**

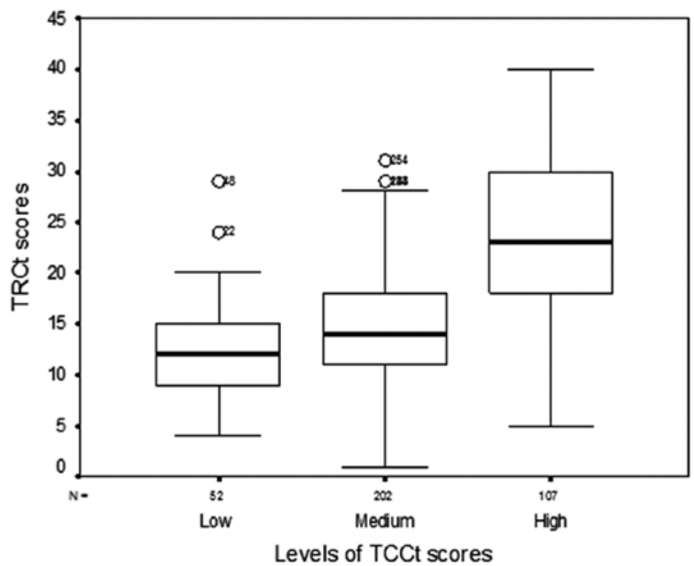


**Figure 2. Normal probability plots of TCCt scores and TRCt scores ($n$ = 361).**

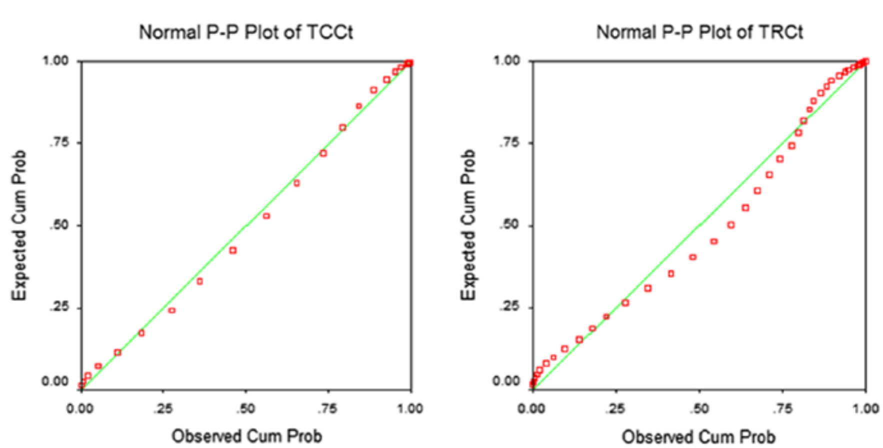

**Table 6. ANOVA of TRCt scores for students with different levels of TCCt scores**

| Source of variation | Sum of square | df | Mean square | *F*-value | Level of significance |
|---|---|---|---|---|---|
| Between groups | 7266.000 | 2 | 3633.000 | 90.353*** | 0.000 |
| Within groups | 14435.164 | 358 | 40.209 | | |
| Total | 21701.164 | 360 | | | |

****F*-value is significant at $p < 0.001$.

The results in Table 6 show that ANOVA was significant, [$F$ (2, 358) = 90.353, $p < 0.001$], indicating that there was a highly significant statistical difference in the mean of the TRCt score among subjects of different levels of TCCt scores. This implies there were significant differences among subjects with different levels of understanding of chemical concepts in their representational competence in chemistry.

Post hoc tests for multiple comparisons, the Scheffe tests, were subsequently performed to determine which pair of means was significantly different.

Results of the Scheffe test (Table 7) revealed significant differences between two pairs of TRCt means: high versus low level of TCCt scores and high versus medium level of TCCt scores, at $p < 0.001$. The mean difference between the pair of medium versus low level of TCCt scores was statistically not significant.

### *3.2. Comparing students of different levels of understanding of chemical representations in their representational competence*

The number of subjects taking the TCR and TRC were 379 and 384, respectively. However, only those who took both the tests ($n$ = 352) are included in this comparison.

For the purpose of comparison, the subjects have been categorized into three levels of understanding of chemical representations based on their TCRt scores. Ranges for the low (L), medium (M), and high (H) groups are based on quartiles of their TCRt scores. Sample size for the low, medium, and high groups are $n$ = 61, 189, and 102, respectively.

Table 8 gives a comparison of students of different levels of understanding of chemical representations in their representational competence.

**Table 7. Multiple comparisons (post hoc Scheffe Tests) of TRCt mean scores**

| Levels of TCCt score (pairs of groups compared) | Mean difference | Standard error | Level of significance |
|---|---|---|---|
| High versus Low | 11.35*** | 1.073 | 0.000 |
| High versus Medium | 9.28*** | 0.759 | 0.000 |
| Medium versus Low | 2.08 | 0.987 | 0.111 |

***The mean difference is significant at $p < 0.001$.

**Table 8. A comparison of students of different levels of understanding of chemical representations in their representational competence**

| Levels of TCRt score | *n* | TRCt Score | | | |
|---|---|---|---|---|---|
| | | Mean | SD | Minimum | Maximum |
| Low | 61 | 13.59 | 5.433 | 3 | 29 |
| Medium | 189 | 16.17 | 6.961 | 2 | 36 |
| High | 102 | 20.14 | 8.879 | 1 | 40 |
| Total | 352 | 16.87 | 7.676 | 1 | 40 |

Graphically, the representational competence of subjects with different levels of understanding of chemical representations can be compared using box plots (Figure 3).

Normal probability plots of TCRt scores and TRCt scores ($n$ = 352) show that distribution of TCRt scores gives a normal distribution while distribution of TRCt scores follows closely a normal distribution (Figure 4). This shows there is little or no violation of normality of data. Hence, ANOVA could be performed.

Table 9 presents the results of the one-way ANOVA of the TRCt score for the three groups with different levels of TCRt scores.

**Figure 3. Box plots of TRCt scores for three levels of TCRt scores.**

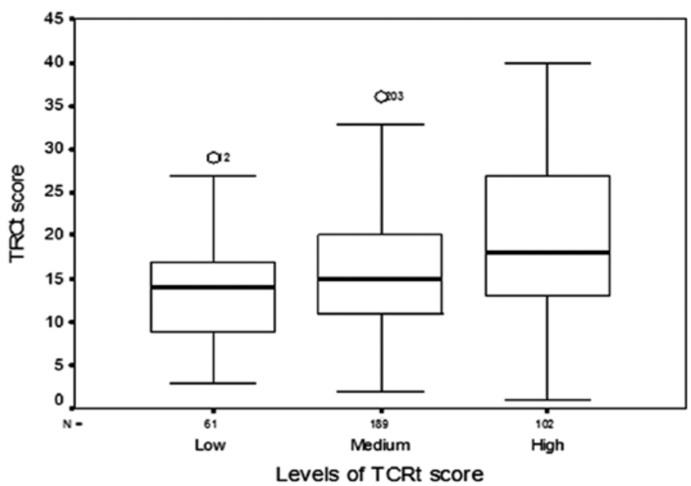


**Figure 4. Normal probability plots of TCRt scores and TRCt scores ($n$ = 352).**

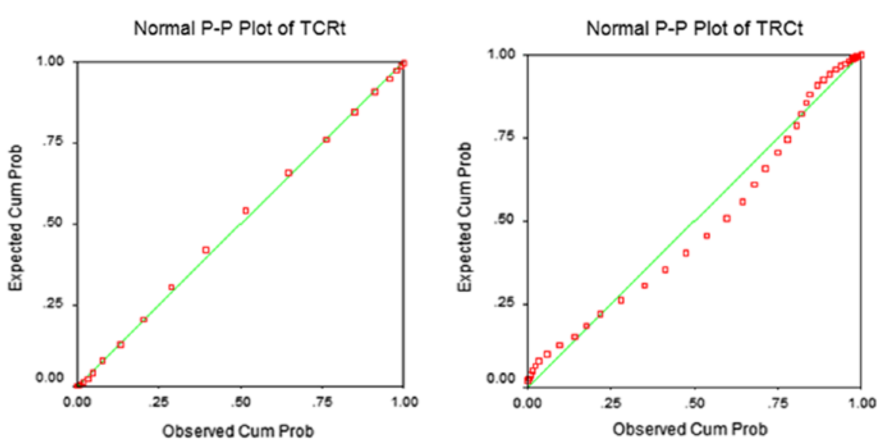


**Table 9. ANOVA of TRCt scores for students with different levels of TCRt scores**

| Source of variation | Sum of square | df | Mean square | *F*-value | Level of significance |
|---|---|---|---|---|---|
| Between groups | 1837.833 | 2 | 918.916 | 17.021*** | 0.000 |
| Within groups | 18841.415 | 349 | 53.987 | | |
| Total | 20679.248 | 351 | | | |

***$F$-value is significant at $p < 0.001$.

**Table 10. Multiple comparisons (post hoc Scheffe Tests) of TRCt mean scores**

| Levels of TCRt score (pairs of groups compared) | Mean difference | Standard error | Level of significance |
|---|---|---|---|
| High versus low | 6.55*** | 1.189 | 0.000 |
| High versus medium | 3.97*** | 0.903 | 0.000 |
| Medium versus low | 2.58 | 1.082 | 0.060 |

***The mean difference is significant at $p < 0.001$.

The results in Table 9 show that ANOVA was significant, [$F$ (2, 349) = 17.021, $p < 0.001$]. This indicates there were significant differences among subjects with different levels of understanding of chemical representations in their representational competence in chemistry.

Post hoc tests for multiple comparisons, the Scheffe tests, were subsequently performed to determine which pair of means was significantly different.

Results of the Scheffe test (Table 10) revealed significant differences between two pairs of TRCt means: high versus low level of TCRt scores and high versus medium level of TCRt scores, at $p < 0.001$. The mean difference between the pair of medium versus low level of TCRt scores was statistically not significant.

## 4. Discussion

The mean TCCt score of 45.60%, which falls below 50%, was rather low. Based on this score, it can be inferred that the overall levels of understanding of basic chemical concepts for this sample is unsatisfactory. The mean TCRt score of 51.75%, which is slightly above 50%, can be considered average. Based on this score, it can be deduced that the overall levels of understanding of chemical representations for this sample is satisfactory. The mean TRCt score of 42.25% was also low. This indicates that the overall level of representational competence in chemistry for this sample is unsatisfactory.

The means reported in Table 5 show that students with a high level of TCCt score registered a much higher mean (23.74) in their TRCt score compared to the other two groups. The mean score of 23.74 almost double that of the low group (12.38). The results indicate that students with a high level of TCCt score outperformed the other two groups in their TRCt score. This implies that students with a high level of understanding of chemical concepts demonstrated the highest overall level of representational competence. The relatively small difference in the means (mean difference = 2.08) between students with a medium level of TCCt score (mean = 14.46) and those with a low level of TCCt score (mean = 12.38) implies that these two groups of students do not differ much in their representational competence. Additionally, the relatively higher standard deviation (SD = 7.870) of the TRCt score of the high group suggests there is more variation in representational competence among the subjects within the high group, as compared to the low group (SD = 4.598) and the medium group (SD = 5.813).

Across the groups, the box plot (Figure 1) shows that subjects with a higher level of TCCt scores register higher TRCt scores. This is evident from the value of the median (the thick line within each box) and the maximum TRCt score (the upper whisker of each box), which is lowest for the low group and highest for the high group. While it is also obvious from Figure 1 that subjects with a high level of TCCt scores outperformed the other two groups in their representational competence (as reflected in their TRCt scores), there is relatively little difference in performance between subjects with low and medium levels of TCCt scores, in their representational competence. Although the maximum TRCt score for the medium and the low group (Figure 1) seem to differ greatly, the median for these two groups does not differ much. Essentially, the low and the medium groups seem about equal in their representational competence.

For a box plot (Figure 1), the longer the box (or inter quartile range), the greater is the spread or standard deviation of the TRCt scores. Within the group, in terms of the distribution of TRCt scores, the small box sections for the low and the medium groups also indicate these two groups which show little variation in their representational competence within their respective groups. Meanwhile, the high group has substantially more dispersion, as indicated by the much larger box section in the box plot. This suggests that subjects in the high group show more variation in their representational competence within the group.

The researcher was also alerted by the presence of outliers by the box plots, as indicated by the notations at the upper portion of each plot beyond the whiskers (Figure 1). However, the outliers were not deleted as statistical tests show that the outliers have no impact in the group differences.

One-way ANOVA, $F$ (2, 358) = 90.353, $p < 0.001$, and subsequently the *post hoc* Scheffe tests revealed students with a high level of understanding of chemical concepts had significantly higher overall level of representational competence compared to both the medium and the low groups, at $p < 0.001$. However, students with medium and low levels of understanding of chemical concepts showed no significant difference in their overall levels of representational competence (Tables 6 and 7).

The means reported in Table 8 show that subjects with a high level of TCRt score registered the highest mean (20.14) in their TRCt score, while students with a low level of TCRt score obtained the lowest mean (13.59) in their TRCt scores. This seems to imply that subjects with a high level of understanding of chemical representations demonstrated the highest overall level of representational competence. In terms of distribution of TRCt scores, the relatively higher standard deviation (SD = 8.879) of the TRCt score of the high group suggests there is more variation in representational competence among the subjects within the high group, as compared to the low group (SD = 5.433) and the medium group (SD = 6.961).

Figure 3 shows that subjects with higher levels of TCRt scores register higher TRCt scores. This is indicated by the medians and the maximum TRCt score, which is lowest for the low group and highest for the high group.

Although Figure 3 shows that subjects with a high level of TCRt scores performed better compared to the other two groups in their representational competence, the performance among the three groups with different levels of TCRt scores in their representational competence does not differ greatly across the groups. In particular, the low group and the medium group are essentially equal in their representational competence.

In terms of distribution of TRCt scores within the group, only the high group show more variation in their TRCt scores or representational competence (as indicated by the larger box section in the box plot). The low group and the medium group show little variation in their representational competence within their respective groups.

The presence of outliers was indicated by the notations at the upper portion of each plot beyond the whiskers (Figure 3). However, the outliers were retained as the statistical tests show that the outliers have no impact in the group differences.

One-way ANOVA, $F$ (2, 349) = 17.021, $p < 0.001$, and subsequently the *post hoc* Scheffe tests revealed students with a high level of understanding of chemical representations also had significantly higher overall level of representational competence compared to both the medium and low groups at $p < 0.001$, while those with medium and low levels of understanding of chemical representations showed no significant difference in their overall levels of representational competence (Tables 9 and 10).

Comparing Figures 1 and 3, it can be seen that students' level of understanding of basic chemical concepts especially the high group (H) has a much bigger impact on their level of representational competence (TRCt score), as compared to their level of understanding of chemical representations, on their level of representational competence (TRCt socre).

Additionally, a comparison of Tables 6 and 9 reveals that the differences between the high and medium/low groups are significant. Table 6 shows that ANOVA analysis of TRCt scores for students with different levels of TCCt scores gives a much higher *F*-value (90.353) compared to Table 9 which shows that ANOVA analysis of TRCt scores for students with different levels of TCRt scores (*F*-value = 17.021).

The above findings are justified as the regression model derived in another study (Sim & Daniel, 2012) with the same sample reported that while understanding of basic chemical concepts accounts for 55.5% of the variance of representational competence, understanding of chemical representations only accounts for 2.2% of the variance of representational competence.

## 5. Conclusion and implications

Findings of the study revealed that students with a high level of understanding of (1) basic chemical concepts, and (2) chemical representations outperformed the medium and the low groups, while the low and medium groups do not differ much, in their representational competence. Such findings suggest that a high level of understanding of basic chemical concepts and chemical representations are prerequisite for learners to demonstrate a high overall level of representational competence. In this respect, the low overall levels of understanding of basic chemical concepts of the participants, and their average level of understanding of chemical representations, are cause for concern.

Nevertheless, findings also show that students' level of understanding of basic chemical concepts has a much bigger impact on their overall level of representational competence as indicated by the TRCt score, as compared to their level of understanding of chemical representations, on their overall level of representational competence.

As representational competence is a necessary skill to be acquired by every chemistry student, the findings highlight an urgent need to enhance understanding of basic chemical concepts among Form 4 science students before they can proceed further in their chemistry studies. More time and effort should be devoted to teaching and learning of basic chemical concepts, as this lack of conceptual understanding could impede their representational competence.

**Funding**
The authors received no direct funding for this research.

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**Citation information**
Cite this article as: Representational competence in chemistry: A comparison between students with different levels of understanding of basic chemical concepts and chemical representations, J.H. Sim & E.G.S. Daniel, *Cogent Education* (2014), 1: 991180.

**Notes**

1. subjects whose TRCt scores were in the bottom 25%.
2. subjects whose TRCt scores were in the middle 50%.
3. subjects whose TRCt scores were in the top 25%.

**References**

Arasasingham, R. D., Taagepera, M., Potter, F., & Lonjers, S. (2004). Using knowledge space theory to assess student understanding of stoichiometry. *Journal of Chemical Education, 81*, 1517–1523. http://dx.doi.org/10.1021/ed081p1517

Chi, M., Feltovich, P., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Science, 5*, 121–152. http://dx.doi.org/10.1207/s15516709cog0502_2

Chittleborough, G. D., & Treagust, D. F. (2007). The modelling ability of non-major chemistry students and their understanding of the sub-microscopic level. *Chemistry Education Research and Practice, 8*, 274–292. http://dx.doi.org/10.1039/b6rp90035f

Davidowitz, B., Chittleborough, G. D., & Murray, E. (2010). Student-generated submicro diagrams: A useful tool for teaching and learning chemical equations and stoichiometry. *Chemistry Education Research and Practice, 11*, 154–164. http://dx.doi.org/10.1039/c005464j

Ebel, R. L. (1993). *Essenials of educational measurement* (5th ed.). Englewood Cliffs, NJ: Prentice-Hall.

Gabel, D. L. (1999). Improving teaching and learning through chemistry education research: A look to the future.

*Journal of Chemical Education, 76*, 548–554. http://dx.doi.org/10.1021/ed076p548
Heitzman, M., & Krajcik, J. (2005, April). *Urban seventh-graders' translations of chemical equations: Which parts of the translation process do students' have trouble?* Paper presented at the annual meeting of the National Association for Research in Science Teaching (NARST), Dallas, TX.
Hoffmann, R., & Laszlo, P. (1991). Representations in chemistry. *Angewante Chemie, 30*(1), 1–16.
Johnstone, A. H. (1982). Macro- and micro-chemistry. *School Science Review, 64*, 377–379.
Johnstone, A. H. (1991). Why is science difficult to learn? Things are seldom what they seem. *Journal of Computer-Assisted Learning, 7*, 75–83. http://dx.doi.org/10.1111/j.1365-2729.1991.tb00230.x
Johnstone, A. H. (1997). Chemistry teaching—Science or alchemy? 1996 brasted lecture *Journal of Chemical Education, 74*, 262–268. http://dx.doi.org/10.1021/ed074p262
Johnstone, A. H. (2006). Chemical education research in Glasgow in perspective. *Chemistry Education Research and Practice, 7*, 49–63. Retrieved February 2, 2007, from http://www.rsc.org/uchemed/uchemed.htm http://dx.doi.org/10.1039/b5rp90021b
Keig, P. F., & Rubba, P. A. (1993). Translation of representations of the structure of matter and its relationship to reasoning, gender, spatial reasoning, and specific prior knowledge. *Journal of Research in Science Teaching, 30*, 883–903. http://dx.doi.org/10.1002/(ISSN)1098-2736
Kozma, R. (2000). *Representation and language: The case for representational competence in the chemistry curriculum*. Paper presented at the Biennial Conference on chemical education. Ann Arbor, MI.
Kozma, R. B., & Russell, J. (1997). Multimedia and understanding: Expert and novice responses to different representations of chemical phenomena. *Journal of Research in Science Teaching, 34*, 949–968. http://dx.doi.org/10.1002/(ISSN)1098-2736
Kozma, R. B., & Russell, J. (2005). Chapter 7—Modeling students becoming chemists: Developing representational competence. In J. K. Gilbert (Ed.), *Visualization in science education* (pp. 121–145). Dordrecht: Springer. http://dx.doi.org/10.1007/1-4020-3613-2
Mehrens, W. A., & Lehmann, I. J. (1973). *Measurement and evaluation in education and psychology*. New York, NY: Holt, Rinehart & Winston.
Nitz, S., Nerdel, C. & Prechtl, H. (2012, August, 28–31). *Modeling the relationship between representational competence and domain knowledge*. Paper presented at the 2012 EARLI Special Interest Group 2 meeting, Grenoble, France.
Nurrenbern, S. C., & Pickering, M. (1987). Concept learning versus problem solving: Is there a difference? *Journal of Chemical Education, 64*, 508–510. http://dx.doi.org/10.1021/ed064p508
Parnafes, O. (2010). Representational practices in the activity of student-generated representations (SGR) for promoting conceptual understanding. In *Proceedings of the Eighth International Conference of the Learning Sciences*. Chicago, IL: ICLS.
Parnafas, O., Aderet-German, T., & Ward, T. T. (2012). *Learning for understanding: An instructional approach for promoting learning and understanding*. A paper presented at the annual meeting of the American Educational Research Association, Vancouver, Canada.
Sim, J. H., & Daniel, E. G. S. (2012). Chapter 15: Predictor variables of representational competence in chemistry: Deriving a regression model. In A. N. Zain & D. R. Peter (Eds.), *Transforming school science education in the 21st century* (pp. 148–161). Penang: SEAMEO-RECSAM.
Stieff, M. (2011). Improving representational competence using molecular simulations embedded in inquiry activities. *Journal of Research in Science Teaching, 48*, 1137–1158. http://dx.doi.org/10.1002/tea.20438
Stieff, M., & McCombs, M. (2006). Increasing representational fluency with visualization tools. In *International Conference of the Learning Sciences* (pp. 730–735). Indiana University, Bloomington, IN.
Treagust, D. F., Chittleborough, G., & Mamiala, T. L. (2003). The role of submicroscopic and symbolic representations in chemical explanations. *International Journal of Science Education, 25*, 1353–1368. http://dx.doi.org/10.1080/0950069032000070306
Wu, H. K. (2003). Linking the microscopic view of chemistry to real-life experiences: Intertextuality in a high-school science classroom. *Science Education, 87*, 868–891. http://dx.doi.org/10.1002/(ISSN)1098-237X
Wu, H. K., Krajcik, J. S., & Soloway, E. (2001). Promoting understanding of chemical representations: Students' use of a visualization tool in the classroom. *Journal of Research in Science Teaching, 38*, 821–842. http://dx.doi.org/10.1002/(ISSN)1098-2736
Wu, H. K., & Shah, P. (2004). Exploring visuospatial thinking in chemistry learning. *Science Education, 88*, 465–492. http://dx.doi.org/10.1002/(ISSN)1098-237X

## Appendix A

### Sample questions from the tests (TCC, TCR, and TRC)

#### *Test of chemical concepts (TCC)*

*Part A: True or false items*
Read each statement carefully and decide whether the statement is TRUE or FALSE. Indicate your choice by CIRCLING T or F on the Answer Sheet (not shown here).

(1) The simplest substances in chemistry are atoms.

(2) The particles in a compound can be atoms, molecules, or ions.

*Part B: Multiple-choice questions*
Choose the best answer for each item, then mark your choice by CIRCLING either A, B, C, or D on the Answer Sheet provided.

What is the number of valence electrons of an oxide ion, $O^{2-}$?

A. – 2 B. 4 C. 6 D. 8

***Test of chemical representations (TCR)***

*Part A: True or false items*
Read each statement carefully and decide whether the statement is TRUE or FALSE. Indicate your choice by CIRCLING T or F in the Response Sheet provided separately.

(1) A hydrogen molecule can be represented either as $H_2$ or 2H.
(2) $C_6H_{12}O_6$ is glucose.

*Part B: Multiple-choice questions*
Choose the best answer for each item. Then mark your choice by CIRCLING the letter A, B, C, or D in the Response Sheet provided.

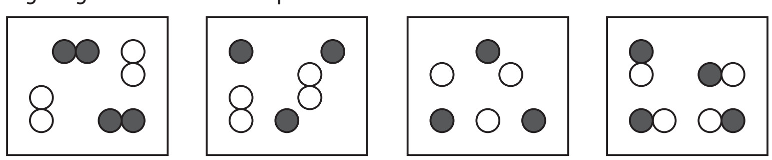
How many atoms of hydrogen are represented in the formula $(NH_4)_2HPO_4$?

A. 5 B. 7 C. 8 D. 9

***Test of representational competence (TRC)***

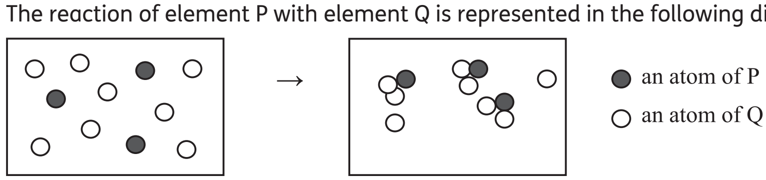
*Part A: Multiple-choice questions*
Choose the best option for each item, then mark your choice by CIRCLING either A, B, C, or D on the Answer Sheet provided (not shown here).

A mixture of gases contains only atoms of helium and molecules of hydrogen. Which of the following diagrams is the best representation of the mixture?



(A) (B) (C) (D)

The reaction of element P with element Q is represented in the following diagram:




Which equation best describes this reaction?

A. $3P + 8Q \rightarrow 3PQ_2 + 2Q$
B. $P_3 + Q_8 \rightarrow 3PQ_2 + Q_2$
C. $P + Q \rightarrow 3PQ_2 + 2Q$
D. $P + 2Q \rightarrow PQ_2$ (Nurrenbern & Pickering, 1987, p. 509)

*Part B: Short free response format*
Write your answers in the spaces provided for each question.

Magnesium reacts with an acidic solution to produce hydrogen. The following equation describes the reaction:

$$Mg(s) + 2H^{+}(aq) \rightarrow Mg^{2+}(aq) + H_2(g)$$

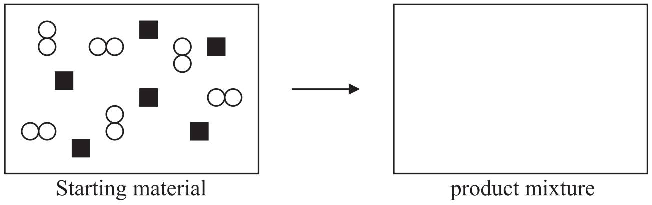
In the above equation, the number “2” appears three times, with different meaning in each case. **Explain** the meaning of the number “2” in:

(i) $2H^{+}(aq)$

(ii) $Mg^{2+}(aq)$

(iii) $H_2(g)$

The equation for a reaction is: $2S + 3O_2 \rightarrow 2SO_3$. Consider a mixture of S (■) and $O_2$ (○○) in a closed container as illustrated below:




Assuming complete reaction,

(a) **Draw** a molecular-level representation of the product mixture in the box provided.

(b) **Explain** how you arrived at this representation.

(Arasasingham, Taagepera, Potter, & Lonjers, 2004, p. 1523)