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Effective Applications of Content Analyses for Students' Molecular Particulate Understanding-- Thermal Decomposition of Calcium Carbonate

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Abstract

This study aimed at effective methods of content analyses to analyze and approach students' conceptual responses of molecular particulate properties in the thermal decomposition of calcium carbonate. It elucidated the matter states, temperature, pressure and volume by the three-tier diagnostic tool in chemistry learning. All students were required to take the diagnostic assessment during 2013-2014 academic years. This study presented important characteristics based on participants' responses after they were formally instructed on the molecular particulate learning. As an innovative application of diagnostic assessments, this study summarized four statistical results. First of all, it set up high validity and reliability with three-tier tests for students' diagnostic tool. Secondly, students' low achievement should be assessed because of their misconceptions in molecular particulate. For the third statistical result of conceptual answers, this study attributed students' learning assessments to their conceptual lack of molecular particulate behavior. Fourthly, several students' responsive reasons were examined for their incorrect understanding in molecular particulate behavior. To sum up, chemical applications of three-tier tests in content analysis for molecular particulate properties could detect students' lagging problems of conceptual learning and offer a new horizon for approach of molecular particulate properties in the specific example.

Introduction

The implements of content analysis aligned with the three-tier diagnostic tool would be a pioneering approach in students' molecular particulate learning. Science educators, researchers and teachers often got into dilemma in making effective assessments to enhance students' conceptual learning for teaching effectiveness [1]. At the present, most college students simply learned to memorize algorithms and lower-level content in order to pass examinations without developing a meaningful understanding of the higher-level chemical concepts and unifying principles[2]. Scholars [2-3] had found out that even students could solve simple algorithmic chemistry problems, yet they still had difficulty in answering conceptual problems on the same chemistry units, especially when they came up with these conceptual problems of molecular particulate in detail [4,5]. Furthermore, much misunderstanding of fundamental chemistry principle hinders students' further effective learning for pursuing concept constructions [6-8]. Enhancing students' understanding of chemistry concepts and process skills, rather than only teaching lower-level chemical knowledge, has become a major goal for chemistry educators, researchers and teachers [9]. Pickering [10] suggested that the phenomenon might be due to the students' lack of exact scientific knowledge, rather than a lack of real internal ability. Sawrey [11]and Niaz [6] conducted studies using symbols and numbers of particles successfully for conceptual questions.

Now let us return to the role of scholars' improving approach for the link of assessments and application in chemistry equilibrium. Recently scholars [12, 13] emphasized that students could not hold clear conceptions, mainly because of their inability to answer conceptual questions without scientific reasoning skills of molecular particulate. Although several researches [2, 3, 5, 10, 14] have explored the specific question of molecular chemistry, few have focused their subject on students' content analysis in terms of different choice levels for molecular particular understanding. This study takes up the approach of content analyses in detail to analyze students' conceptual responses of three-tier diagnostic tests for molecular particulate properties in chemistry equilibrium.

Research questions

The purpose of this study offers the key of content analyses to analyze students' conceptual understanding of molecular particulate properties for three-tier diagnostic tests in the thermal decomposition of calcium carbonate. Based on the above purpose, this study proposes three major research questions in the following:

1. What are the most confused choices for college students' understanding of molecular particulate properties?
2. Does students' correct answer correspond to their validity reason of particular properties in the thermal decomposition of calcium carbonate?
3. Does students' choice of incorrect answer manifest their misunderstanding of particular properties in the thermal decomposition of calcium carbonate?

Theoretical Perspectives

Three-tier diagnostic assessment in chemistry

Researches on three-tier diagnostic assessment in chemistry equilibrium have developed a remarkable field for data tool tests on students' misconceptions domain of the characteristic knowledge [15]. The dynamic aims of diagnostic assessment supplied educators, researchers and teachers with chemistry intelligence about what college students already acquired their questions and were able to build up answers [16]. Researchers [17-19] used diagnostic tests in chemistry education to diagnose students' misconceptions and differentiate their answers from a lack of knowledge. This approach based on three-tier diagnostic tests which followed

Treagust's two-tier tests [17-20]. The diagnostic assessment could assist students in their efforts to develop a more comprehensive understanding of the chemistry conceptions for chemical implemented curriculum. Therefore, the majority of this study incorporated the advantage of three-tier diagnostic tests and used content analyses methods in order to detect students' reasons for selecting molecular levels in chemical equilibrium.

Application of content analyses

The overall range of content analyses included (1) conceptual analysis, (2) edition or compilation analysis, (3) descriptive narration analysis, (4) interpretative comparative analysis, and (5) universal analysis [21-23]. The conceptual analysis was one of the most important content analyses. It described general or virtual meaning and confirmed the difference from conceptions. Another effective function for compilation, universal analysis offered the authentic interpretation by academic or philosophic analyses.

This study adopted both the conceptual analysis and universal analysis by three-tier diagnostic tests in attempting to analyze students' responses and conceptions of molecule particulate properties in chemical equilibrium. The integrated construction of quantitative and quality analyses presented students' tendency of conceptions, learning situations, and new aspects in thermal decomposition of calcium carbonate.

Methodology

Participants

All participants in this study were college students from four different technology universities in Taiwan. 188 students were recruited from four different departments, such as chemical materials, environmental engineering, electronic engineering and mechanical engineering. They were divided into four groups, such as M (department of chemical materials, 66 ns), N (department of environmental engineering, 43 ns), O (department of electronic engineering, 58 ns) and P (department of mechanical engineering, 21 ns), in order to compare their understanding performance of thermal decomposition of calcium carbonate. A stratified procedure was used to eliminate voids in the sampling frames. Four different group students completed an 8 hour-learning in the four-week chemistry equilibrium program courses and exhibited the same extent in the entrance examination during 2013-2014 academic years. After completing the course of chemistry equilibrium, students were asked to answer a set of three-tier diagnostic tests and to explain what would happen for molecular particular level in their choice of the tests (shown in Fig. 1).

Function and quality of three-tier diagnostic tests

Three-tier diagnostic tests of this study (see Table 1) were based on Treagust's two-tier tests [17-19] and developed a more implemented comprehensive understanding in chemistry curriculum. The function of the first tier was a typical multiple-choice question to estimate the descriptive or respondent chemistry knowledge. The function of the second tier provided students to select or write a valid reason for the first-tier response [24], and the function of the third tier required students to evaluate concept understanding for the strength of confident responses in chemistry equilibrium question [24-26]. In order to develop and construct validity of three-tier tests, this study extracted one item (see Table 2) from 17 three-tier questions by Su [27]. The diagnostic test consisted of the mean difficulty indices 0.54, which indicated that the distribution of tests belonged to medium and easy of difficulty, and the mean discrimination indices 0.37 which were signs of good standard tests [28]. The Cronbach's α for the first-tier, the two-tier, and the three-tier scores were 0.629, 0.773, and 0.872, respectively. Compared to average criterion tests, the three-tier tests had higher reliability than other reported tests [28-29].

Table 1**.** Different functions of the three-tier tests in chemistry equilibrium

Test	Function	Response of knowledge process
The first tier	Content knowledge	to estimate the descriptive or respondent chemistry knowledge
The second tier	Reason knowledge	to assess the explanatory knowledge or mental models of molecular particulate level
The third tier	Confidence rating	to evaluate concept understanding for the strength of confident responses in chemistry equilibrium question

Reference seen in context

Data analyses

This study employed the method of content analyses to analyze and approach students' conceptual responses for molecular particulate properties in chemistry equilibrium. All quantitative data were listed by the SPSS of Windows 12.0 software for statistical analyses.

Treatments

The chemistry equilibrium course was selected for the three-tier tests to elucidate the molecular particulate properties in this study. A heterogeneous equilibrium, such as calcium carbonate was heated in a closed vessel and the equilibrium was arrived in the following way:

$$CaCO_{3(s)} \overset{heat}{\rightleftharpoons} CaO_{(s)} + CO_{2(g)}$$

$$K_c = [CO_2] \text{ and } K_p = P_{CO2}$$

Nevertheless, the concentration of one solid, just like its density, was an intensive property and didn't depend on how much of the substance was present [30]. Thus, the value of K_c and K_p didn't depend on how much $CaCO_{3(s)}$ and $CaO_{(s)}$ were present, as long as each of some was present in equilibrium (shown in Fig. 1).

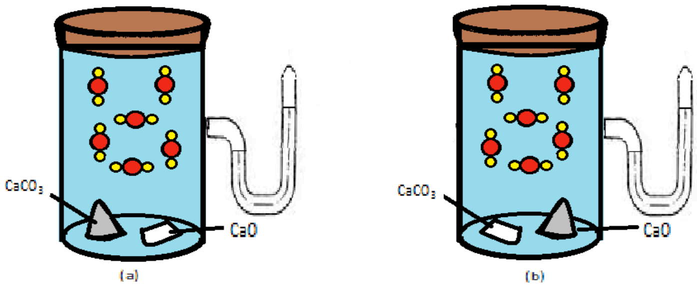

Figure 1. Although the presence of different amounts between $CaCO_3$ and CaO, the equilibrium pressure of CO_2 in both (a) and (b) were the same at the constant temperature for molecular particulate properties in chemistry equilibrium

The chemistry equilibrium course normally involved 2 hours of lecture-demonstration and 2 hours of laboratory inquiry during two weeks. The components for lecture-demonstration were enriched with supplemental resources. The supplementary materials (such as animations and slides), lecture, and demonstration, all combined together to provide a multimedia-learning environment for well-equipped facilities. These components were developed by the author, utilizing design principles in the research literature [31-32]. Six features were involved in the conceptual understanding of molecular particulate properties for three-tier diagnostic tests (shown in Table 2) in the specific example of the thermal decomposition of calcium carbonate:

(1) To analyze the learning goal for the target four groups
(2) To design appropriate three-tier diagnostic tests for assessments
(3) To design multiple applications of three-tier diagnostic tests
(4) To incorporate molecular particulate properties into three-tier diagnostic tests
(5) To divide the participants into four groups for our research project
(6) To access and analyze four group students' responsive percentage

Table 2. The particular properties of three-tier tests in chemistry equilibrium

Tiers	Question
First tier	1.1 Consider this reaction at equilibrium in a closed container: $CaCO_{3(s)} + \text{heat} \rightleftharpoons CaO_{(s)} + CO_{2(g)}$ Which one of the following is ***incorrect***? A. Some $CaCO_{3(S)}$ is added to the equilibrium mixture and the position is not to shift. B. The equilibrium position will shift toward the reactants when the pressure is increased at constant temperature. C. $CaCO_{3(s)}$ is decomposed more and more completely at raised temperature which will cause the equilibrium pressure is increased. D. When the equilibrium position will be reconstructed and partial pressure of CO_2 will be enlarged at the volume is increased at constant temperature*.
Second tier	1.2 Which one of the following is the ***reason*** of your answer to the previous question? A. The equilibrium position will shift to right when the reactant $CaCO_3$ is added. B. The equilibrium position will shift to right when the pressure is increased at constant temperature*. C. The equilibrium position will be reconstructed and partial pressure of CO_2 will be not exchange as the volume is increased at constant temperature. D. The equilibrium position will shift toward reactant as the temperature is raised. E. ________________________________
Third tier	1.3 Are you sure about your answers given to the previous two questions? A. I am sure.* B. I am not sure.

Results and Discussions

Reliability of three-tier diagnostic tests

This study developed high quality three-tier diagnostic tests to analyze and approach students' conceptual responses of molecular particulate properties in chemistry equilibrium. There were three reasons for employing the three-tier tests in this study. First of all, we used the three-tier tests not only to reveal whether a wrong answer was due to a misconception as the two-tier tests, but also to distinguish a misconception from a lack of knowledge. Secondly, because traditional tests (one-tier or two-tier tests) overestimated students' achievement or misconception scores, only three-tier tests could estimate their scores accurately. The Cronbach's α reliabilities coefficient were 0.629, 0.773, and 0.872 among three-tiers respectively in this study. In this study, the correlation between two tiers scores and certainty scores was investigated and a statistical significant positive correlation [r= .323, p< .001], providing evidence of the construct validity. Therefore, three-tier tests may be more valid and reliable tools to estimate students' achievement or misconception. Thirdly, the three-tier tests helped students to understand molecular particulate properties clearly by content analyses in chemistry equilibrium. To sum up, the three-tier tests provided chemistry researchers the opportunity of content analyses with clarity to avoid the wrong explanation for their confused choice of molecular particulate level.

Table 3 showed the results of college students' correct responsive person number percentage for three-tier tests in thermal decomposition of calcium carbonate. The percentages of students' choosing each response were lower-order thinking skills, even if they were measured at four different colleges and departments. In addition, the differences between the percentages of the correct answers from the first tier to all three tiers for four group students were visible. All these differences could be attributed to lack of knowledge, lucky guess or misconception [15]. Three-tier tests provided an opportunity for identifying the percentage of each in Table 3.

Table 3. The analyses of college students 'responsive person number percentage for three-tier tests in chemistry equilibrium

	Correct response person number (%)					
Group(ps)	**Q1.1**	**Q1.2**	**Q1.3**	**one-tier**	**two-tiers**	**three-tiers**
M (66)	11(17)	17(26)	18(27)	11(17)	6(1)	6(1)
N (43)	3(7)	14(33)	10(28)	3(7)	1(2)	1(2)
O (58)	8(14)	16(28)	27(47)	8(14)	2(3)	2(3)
P (21)	8(38)	2(9)	10(48)	8(38)	2(9)	2(9)

Analyses of students' response and explanations

In the research question 1, "what is the most confused choice for college students' explanations of molecular level in thermal decomposition of calcium carbonate?" Students' incorrect selected answer was option (c), chosen by 19-40% of the students in Q1.1. Option (c) was also the most frequent answer for all of the four groups. The most common explanation of students' molecular level described by their thinking would be "$CaCO_3(s)$ is decomposed more and more completely at raised temperature which will cause the equilibrium pressure increase."

In the research question 2, "does college students' selecting the scientific accepted answer provide a validity reason of particular behavior in chemistry equilibrium?" Table 4 showed the results of the content analyses executed students' explanations of molecular particular behavior in thermal decomposition of calcium carbonate of three-tier tests for four group students. Q1.2 option (B) was students' selecting the scientific accepted answer to provide a validity reason of particular behavior in thermal decomposition of calcium carbonate, chosen by 9-33% students of the four groups. N group students' selecting the most scientific accepted answer percentage 33% provided a validity reason of particular behavior in thermal decomposition of calcium carbonate, but the correct answer in Q1.1 was only 7% students, to be false negative misconception[15]. Both option (A) and option (C) in Q1.2 chosen by 16-23%, 24-37% students respectively, were also the most frequent incorrect answers for all of the four group students. Option (A), "The equilibrium position will shift to right when the reactant $CaCO_3$ is added," was the most frequent misconception for the four group students. Students couldn't understand how $CaCO_3$ could affect the equilibrium to shift. Option (C), "The equilibrium position will be reconstructed and partial pressure of CO_2 will be not exchange as the volume is increased at constant temperature," was also the most frequent misconception for the four group students. Students didn't understand that temperature would be the major affect for the equilibrium constant $K= P_{CO2}$ in three-tier tests.

In the research question 3, "does college students' selecting the incorrect answer manifested the incorrect view of particular behavior in thermal decomposition of calcium carbonate?" In Table 4, the correct percentage of the first tier was superior to that of two-tiers, and the correct percentage of two-tiers were superior to that of three-tiers, so that college students' selecting the answer manifested the incorrect view of molecular particular properties in thermal decomposition of calcium carbonate.

Table 4. The analyses of college students' group responsive percentage for three-tier tests in chemistry equilibrium

Question	Answer	**Group(%)**			
Test	Item	**M(N=66)**	**N(N=43)**	**O(N=58)**	**P(N=21)**
1.1	A	16(24)	14(33)	16(27)	6(29)
	B	16(24)	11(25)	11(19)	3(14)
	C	23(35)	15(35)	23(40)	4(19)
	D*	11(17)	3(7)	8(14)	8(38)
1.2	A	15(23)	10(23)	10(16)	4(19)
	B*	17(26)	14(33)	16(28)	2(9)
	C	21(32)	16(37)	16(28)	5(24)
	D	13(19)	3(7)	16(28)	10(48)
1.3	A	18(27)	10(28)	27(47)	10(48)
	B	48(73)	31(72)	31(53)	11(52)

*Answer key

From the above correspondence analyses, we could understand students' learning misconceptions from their advanced questions of molecular particulate for three-tier tests in thermal decomposition of calcium carbonate.

Conclusions and Implications

All 188 students was asked to answer the sampling questions of the three-tier tests for molecular particulate properties in thermal decomposition of calcium carbonate. This study presented important statistical results based on participants' responses after they were formally instructed on the molecular particulate in thermal decomposition of calcium carbonate. As an innovative research, this study accounted for four results: namely to set up high validity and reliability with three-tier tests, to analyze explanations for students' low achievement because of their misconceptions in molecular particulate, to judge students' selecting scientific conceptual answers owe to their behavior of lack molecular particulate, and to propose students' several behavior reasons for incorrect responses of molecular particulate. To sum up, applications of three-tier tests in content analyses for chemical molecular particulate properties could detect students' lagging problems of conceptual learning and offer a new horizon to approach for molecular particulate properties in thermal decomposition of calcium carbonate. Since the conclusions from this study are based only on the responses of 188 college students who explicitly specified important molecular particulate properties, these conclusions should be viewed cautiously. Notwithstanding, development of the three-tier tests, in order to establish prosperous learning environments of molecular particulate properties in chemistry, free from the impediments of learning misconception are our future longitude study purposes. We manifest a diagnostic tool for three-tier tests that will help both students and teachers to get involved in meaningful and interesting learning.

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References

[1] Bell, B., "Handbook of research on science education", Mahwah, NJ: Lawrence Erlbaum Associates, pp. 965-1006 (2007).

[2] Nakhleh, M. B., *Journal of Chemical Education,* 70(1), 52-55 (1993).

[3] Nurrenbern, S. C.; Pickering, M., *Journal of Chemical Education*, **64**, 508-510 (1987).

[4] Sere, M., *Eur. J. Sci. Educ.*, **40**, 299-309 (1982).

[5] Sanger, M. J.; Phelps, A. J., *Journal of Chemical Education*, **84**, 870-874 (2007).

[6] Niaz, M., *International Journal of Science Education*, **17**, 343-355 (1995).

[7] Coll R.K.; Treagust D.F., *Research in Science Education*, **31**, 357-382 (2001).

[8] Coll, R.; Treagust, D., *Australian Science Teachers' Journal*, **48**(1), 24-32 (2001).

[9] Ardac, D.; Sezen, A.H., *Journal of Science Education and Technology*, **11**, 39-48 (2002).

[10] Pickering, M., *Journal of Chemical Education*, ***67***(3), 254-255 (1990).

[11] Sawrey, B. A., *Journal of Chemical Education,* **67**, 253-255 (1990).

[12] Cracolice, M.C.; Deming, J.C.; Ehlert, B., *Journal of Chemical Education*, **85**, 873-878 (2008).

[13] Sanger, M. J.; Vaughn, C. K.; Binkley, D. A., *Journal of Chemical Education,* **90**, 700-709 (2013).

[14] Sanger, M. J., *Journal of Chemical Education,* **82**, 131-134 (2005).

[15] Arslan, H. O.; Cigdemoglu, C.; Moseley, C., *International Journal of Science Education*, **34**(11), 1667-1686 (2012).

[16] Green, S. K.; Johnson, R. L., "Assessment is essential", New York: McGraw-Hill (2010).

[17] Treagust, D. F., *Res. Sci. Educ.*, **16**, 199–207 (1986).

[18] Treagust, D. F., *Int. J. Sci. Educ.*, **10**,159-170 (1988).

[19] Treagust, D. F., "Diagnostic assessment of students' science knowledge", Mahwah, NJ: Lawrence Erlbaum Associates, pp. 327-346 (1995).

[20] Treagust, D. F.; Chiu, M. H., *Chemistry Education Research and Practice*, **12**, 119-120 (2011).

[21] Hasan, S.; Bagayoko, D.; Kelley, E. L., *Physics Education*, **34**(5), 294-299 (1999).

[22] Bailey,K. D., "Methods of social research, 3rd Ed." New York: Free Press, p533 (1987).

[23] Babbie, E., "The Practice of Social Research, 10th ed." CA: Wadsworth (2004).

[24] Eryilmaz, A.; Surmeli, E. from http://www.fedu.metu. edu.tr/ufbmek-5/bkitabi/PDF/Fizik/Bildiri/t110d.pdf, Retrieved April 5 (2004).

[25] Caleon, I.; Subramaniam, R., *International Journal of Science Education*, **32**(7), 939-961 (2010).

[26] Pesman, H.; Eryilmaz, A., *The Journal of Educational Research*, **103**, 208-222 (2010).

[27] Su, K. D., *Inderin Journal of Applied Research,* **4**(12), 281-283 (2014).

[28] Ebel, R.L.; Frisbie, D. A., “Essentials of educational measurement (5^{th} Ed.) Englewood Cliffs”, NJ: Prentice-Hall (1991).

[29] Crocker, L.; Algina, J.; Orlando, F. L., “Introduction to classical and modern test theory”, Holt: Rinehart and Winston (1986).

[30] Chang, R., “General Chemistry 3rd ed.”, New York: NY (2003).

[31] Ainsworth, S.E., *Computers and Education*, **33**, 131-152 (1999).

[32] Yore, L. D.; Treagust, D. F., *International Journal of Science Education,* **28**, 291-314 (2006).