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A NEW ASSESSMENT OF HOCS-ORIENTED LEARNING FOR STUDENTS' HIGHER-ORDER THINKING ABILITIES BY MARZANO'S TAXONOMY

King-Dow Su

Abstract. *This research focuses on students' higher-order cognitive skill (HOCS)-oriented learning to construct effective hierarchical thinking abilities in their chemical particulate nature of matter. For in-depth knowledge and profound understanding, this research deals with students' positive developments towards HOCS with a special guidance to Marzanos' taxonomy. The methodology starts from the retrieval and comprehension of HOCS-centered assessment instrument to students' analysis and knowledge utilization of transitional performances. 326 participants were assigned to take natural science curriculum in 2019 academic year. With the help of 7 scholars' implements, the importance of content validity and inter-rate reliability were constructed through instrument developments of students' HOCS performances. All research results indicated that more distributions of HOCS thinking abilities reached up to the target response of 38.0% analysis task and 27.30% knowledge utilization in Marzanos' spectrum. This research is beneficial and advantageous that students will be capable of additional learning efficiency in their multiple interactive engagements with academic resources and suggestions from instructors, researchers, and science educators.*

Key words: *HOCS-oriented learning, knowledge utilization, Marzanos' taxonomy, particulate nature of matter*

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Introduction

At the initial orientation, students have more opportunities to accept a new strategy for HOCS-oriented learning in Marzanos' taxonomy. To cultivate students' founding of HOCS, more challenges exist with students' textual designs. As a dynamic learning goal in the 21st century, many educators have pointed that HOCS-oriented learning becomes a meaningful development to find out students' constructions of cognitive knowledge and global competitiveness (Ghani et al., 2017). Innovative learning, critical thinking and problem-solving are accepted as three dominant constituents of the context with the guidance of students' HOCS development in chemistry education (Danczak et al., 2017; Ghani et al., 2017). It is more and more significant to trace out students' profound development of scientific knowledge and promote their hierarchical levels of reasoning skills in Marzanos' four cognitive taxonomy -- retrieval, comprehension, analysis, and knowledge utilization, within their total learning processes. Therefore, the presentation of Marzano's four cognitive levels allowed more students to assess their thinking skills more accurately than Bloom's revised taxonomy (remembering, understanding, applying, analyzing, evaluating, and creating) in educational objectives (Anderson & Krathwohl, 2001) when they got stuck on problems with limited reactant mental cognition (Marzano & Kendall, 2007).

All students know that chemistry is one of the four basic constituents in the STEM (science, technology, engineering, and mathematics) fields to pave their comprehensive foundation for hierarchical thinking abilities step by step. Accordingly, there are many advantages on students' STEM developments in recognitive abilities, critical thinking, and problem-solving (Cordray et al. 2009; Toledo & Dubas, 2016). The ideal education of science goal should put emphasis on solving students' conceptual problems and getting meaningful knowledge in terms of hierarchical levels of reasoning skills. Students need to accept their finding of scientific argumentations and construct hierarchical explanations during their chemistry learning process (Norris & Philips, 2012). It becomes more and more urgent tendencies for students to cultivate new HOCS-oriented learning in their scientific problem-solving abilities (Lopez et al., 2014).

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The current proposal for students to foster their HOCS-oriented chemistry text and evaluation instrument needs to set up a background environment for instructors' profound deliverance of chemistry knowledge and conception understanding. In contrast to traditional old-fashioned instructions, the innovations of HOCS-oriented learning not only guide students' problem-solving with algorithmic rules but also activate new conceptual knowledge of chemistry fields (Bransford et al., 2004; Domin & Bodner, 2012). Zoller and Pushkin (2007) have classified clear illustrations into dual HOCS combinations of situational knowledge and strategic knowledge. Students are required to make their accumulations of dual knowledge in order to construct HOCS-based hierarchical levels of reasoning skills in their chemistry learning.

Most functionally of all, students should master their strategic developments of reasoning context and argument ability as an important presentation of HOCS-oriented chemistry learning in particulate nature of matter (PNM). The designs of these strategic developments should go steady with students' abilities of critical thinking in their meaningful chemistry learning process (Danczak et al., 2017). Three important factors, innovative learning, critical thinking and problem-solving (Danczak et al., 2017; Ghani et al., 2017; Zoller & Pushkin, 2007) are included in the textual design for students' achievements of HOCS-oriented learning. For this purpose, students would be associated with HOCS-based hierarchical levels of reasoning skills as the essential knowledge of PNM basic conceptual understanding (Vachliotis et al., 2014). Discussions of stimulating students' motivations and interests will be included as their constructions of HOCS-centered chemistry learning with Marzano's taxonomy for hierarchical levels of chemistry equilibrium.

Cognitive Levels of Marzano's Taxonomy

Many instructors, science educators, and researchers have pointed out the subtle aspects of students' HOCS-oriented development in chemistry education (Vachliotis et al., 2014; Su, 2017, 2020). Essential learning objectives are needed for students to construct higher-order thinking abilities and problem-solving implements in chemistry equilibrium. There are four distributions of students' hierarchical cognitive levels -- retrieval, comprehension, analysis, and knowledge utilization in Marzano's spectrum (Marzano & Kendall, 2007) with brain-based learning. Toledo and Dubas (2016) unanimously noticed that Marzano's taxonomy could describe students' cognitive levels of lower-order and higher-order thinking abilities clearly with the framework of spectrum. Students' lower-order thinking abilities included both retrieval and compression tasks during which students were required to obtain the rule-based learning, the accurate reasoning information and integrated comprehensive understanding. Their higher-order thinking abilities included both analysis and knowledge utilization tasks during which students were required to fulfill the creative-based learning, the dual HOCS combination of situational knowledge and strategic knowledge.

Students were required to analyze their new responses after extensive relations have been added to their knowledge appropriately within the third HOCS stage of Marzanos' spectrum analysis task. Knowledge utilization belonged to the fourth HOCS stage during which students explained more authentic task, transferred new knowledge and raised new learning surrounding by the fulfillment of test items in combinations of situations and strategies (Zoller & Pushkin, 2007). Students' chemistry learning did not come up to be a final stage of HOCS if they didn't build their basic knowledge up to the successful stage of LOCS comprehension task. Students' hierarchical cognitive levels were designed to promote their thinking ability by four distributions of Marzanos' spectrum (Marzano & Kendall, 2007). The fulfillment of this research was based on the framework of spectrum distributions to represent the HOCS-centered assessment instrument and guide students to achieve the learning goals of higher-order thinking abilities in chemistry equilibrium.

Diagnostic Evaluation in Chemistry Equilibrium

Margel et al. (2007) have found that many student's comprehensive evaluation toward PNM was difficult in easily generating more obstacles for learning misconception. A complete PNM understanding of students' evaluations is critical to construct fundamental chemistry equilibrium knowledge and inspire confidence in students' HOCS-oriented learning. As a result, there are functional assessments of research results for students' misconceptions in chemistry equilibrium (Jaber & BouJaoude, 2012; Yezierski & Birk, 2006). Chandrasegaran et al. (2007) claimed that students' misconceptions have limited their chemistry capability of description and interpretation in class. Such students' limited capability would hinder their HOCS learning for more cognitive levels of comprehensive understanding. Therefore, Nyachwaya et al. (2011) have pointed that particle equilibrium was a very important comprehensive foundation of cognitive levels for students' HOCS-oriented learning.

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Students' diagnostic evaluation and assessment had been designed and conducted in the chemistry class to provide teachers information on students' comprehensive understanding in what they were required to do for HOCS-oriented learning (Green & Johnson, 2010). Cheung (2011) used diagnostic assessment in helping both pre-service and in-service teachers' comprehensive understanding about the chemistry of lead-acid battery. Nitko and Brookhart (2011) found that students' diagnostic evaluation could confirm their potential reasoning knowledge and proficient skills in chemistry. The assessment would be designed from students' pretest or questionnaire to carry out their essential demand and capability and to obtain results from observation, analysis of data and learning. Using diagnostic assessment would be helpful for instructors in enhancing students' conceptual understanding toward meaningful learning with individual guidance. To be a dominate factor in identifying students' existing chemistry knowledge (Potgieter et al., 2010), prior knowledge provided a profound foundation for students' systematic investigation with chemistry conceptual development (Potgieter et al., 2010). It would be appropriate for researchers to design systematic test items combined with the diagnosis evaluation in order to assess students' comprehensive HOCS understanding in chemistry equilibrium.

In summary, this research had included a detailed assessment for HOCS-centered evaluation instrument to assess students' comprehensive understanding. The employment of Marzano's taxonomy paved a reliable platform for students to perform four distributions of hierarchical cognitive levels (retrieval, comprehension, analysis, and knowledge utilization) in spectrum. Students were ensured to motivate in building up their cognitive performances with comprehensive coalition and scientific concepts.

Purpose and Research Questions

Based on the above assumption, this research proposed a HOCS-oriented learning strategy for students to take active participations with their alternative assessment in chemistry equilibrium. To promote their thinking abilities, students were encouraged to do problem-solving, critical thinking and innovative learning in accordance with their understanding of hierarchical Marzano's taxonomy assessment instrument. Three basic criteria were proposed as the research questions in the following way:

(1) How to design the HOCS-oriented test items suitalble for students' chemistry thinking abilities by Marzano's taxonomy? (2) How to construct the validity and reliability of HOCS-oriented assessment instrument for students' higher-order thinking abilities? (3) How to evaluate students' Marzano cognitive understanding levels hierarchically in chemistry equilibrium for HOCS-oriented assessment instrument?

Research Methodology

General Background

The basic framework of the HOCS-centered diagnostic evaluation instrument (HODEI) follows four hierarchical levels in Marzano's taxonomy spectrum. Four hierarchical cognitive levels are included as retrieval, comprehension, analysis, and knowledge utilization shown in Figure 1 (Toledo & Dubas, 2016). The detailed discussions of four hierarchical cognitive levels, consist of level 1 (L1) as a retrieval task, level 2 (L2) as a comprehension task, level 3 (L3) as an analysis task and level 4 (L4) as a knowledge utilization task. As the first basic level of the retrieval task, students were required to get needed information exactly through their recognizing, recalling, and executing as their feedback of learning objects. Since the work of the retrieval task didn't treat working memory only to reproduce exactly the same algorithm, without acquiring any significant cognitive control at all, the retrieval task should be attributed to the lower-order thinking skill according to Marzano (Toledo & Dubas, 2016).

The next discussion comes up L2 as the second level of students' comprehensive task. For the required comprehensive work, students would explain the reasoning question, deduce symbolizing conclusion, and make appropriate sense of relating science knowledge. At the L2 of the comprehensive task, what students handled were simply working memory and existing knowledge as part of apprehensive meaning, which all pertained to the comprehensive level of the lower-order thinking skill. When students approached L3 as an analysis task, they would specify their expectant reasons for generalizing, analyzing, classifying, and finding out conceptual knowledge with alternative relations and applications. From the perspective of Marzano's taxonomy, L3 of the analysis task pertained to the higher-order thinking skill.

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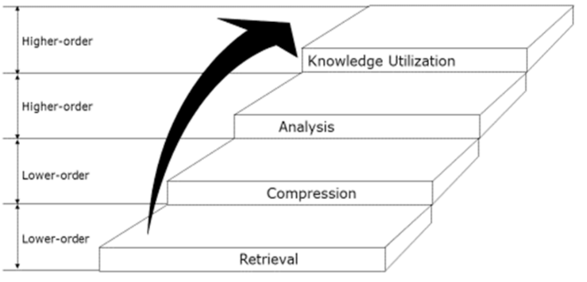
Figure 1
Cognitive levels by Marzano's taxonomy



Another final investigation of the higher-order thinking skill, L4 as a knowledge utilization indicated that students' investigative experiments, solving problems and a knowledge decision help in fostering their learning objectives (see Table 1). Therefore, students aimed at engaging in ultimate knowledge utilization from the existent knowledge to more authentic and creative science information.

Table 1
Students' learning objectives with scores of Cognitive Level tasks in CE

Task	Score	Learning Objectives
Retrieval (L1)	1	Students can list characteristics for recognizing, recalling, and executing as their feedback of learning objects.
Comprehension (L2)	2	Students can clearly explain the reasoning question, deduce symbolizing conclusion, and make appropriate sense of relating science knowledge.
Analysis (L3)	3	Students can specify their expectant reasons for generalizing, analyzing, classifying, and finding out conceptual knowledge with alternative relations and applications.
Knowledge utilization (L4)	4	Students can manage to investigate experiments, solve problems, and make a knowledge decision in fostering their learning objectives.

Note: Learning Objectives were modified from Marzano and Kendall (2007).

Participants of Research and Ethical Approval

A total sampling of 326 participants (including sex distribution 118 males and 208 females; aged distribution from 18 to 21) were selected through two stages of qualification tests as total research sampling from Chung Yuan Christian university, Taiwan, in this research. There were 193 students who took part in the pilot study for developments with the pre-knowledge of basic chemistry equilibrium at the first test stage. Other 133 students engaged in the assessments of the experimental research with HOCS-centered performances at the second stage as the required sample of research. All 326 participants were volunteers with suggestive findings and the anonymous results may be published. Ethical approval was obtained for this research (Taber, 2014) in 2019.

Students' discussion of Marzano's taxonomy consisted of their thinking skills during learning processes precisely classified as both higher-order and lower-order cognitive levels, shown in Figure 1 and Table 1. At the lower-order cognitive levels, students would only acquire and understand the meaningful knowledge entirely, which included retrieval and comprehension tasks. Next for higher-order cognitive levels, students would explore both analysis task and knowledge utilization task with creative information. By Marzano's taxonomy, students would construct a full-scale learning theory between higher-order and lower-order cognitive levels. Basing on Marzano's taxonomy in chemistry learning, the author set up students' design of the diagnosis evaluation instrument to discover 133 students' four hierarchical levels of thinking abilities in this research.

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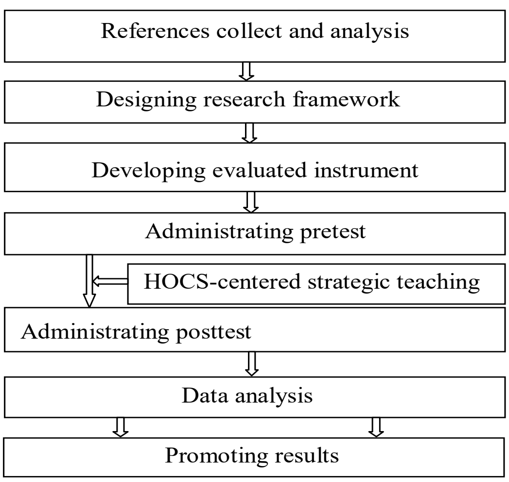
Instrument Design

As an important instrument design, the draft test items of HODEI were adapted for as the assessment resources of chemistry textbooks (Brown, et al., 2018, pp. 666-707). All 25 test items of the first draft had already been scrutinized, deleted and revised by six senior chemistry professors to provide the content validity of students' HODEI test items. They examined and revised all test items in the aspects of the fluencies, correctness, and Marzano's four hierarchal levels. The final results indicated that five test items were deleted with discriminated quality and analogical reasons. To be as functional as possible, all test items would provide correct results without making the mistake to avoid trying the probability that tenders the result linear programming (Griffard & Wandersee, 2001) during the whole editing processes. Furthermore, six renowned chemistry professors also stressed the crucial role of the corresponding HODEI test items with more exact analyses of inter-rater reliability as Kendall's coefficient of concordance (ω). The most influential source for pilot assessment results indicated that 193 university students gathered validity data and marked their major responsive quality in each HODEI test item.

Research Procedures

It was the primary concern to put students' quantitative approach on major statistical findings with their minor development of the qualitative narration. The procedures of constructive designs are summarized in Figure 2 with evaluated HODEI instrument for students' conceptual knowledge. Effective administrating pretest and post-test were assigned in accordance with the chemistry learning objectives within five weeks 2019 academic syllabus.

Figure 2
Flowchart of the Research



Data Analysis

For a complete analysis of HODEI implementation, this research conducted a series of statistical analysis such as, inter-rater reliability(ω) and one-way ANOVA by software 22 SPSS for MS Windows to analyze each test item in this instrument.

Research Results

Quality of Test Items

The major consideration for the validity and reliability of HODEI, the difficulty index of this study confirmed test items *p* value to examine 193 students' pilot results as shown in Table 2. The main statistics of *p* values followed

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the following 4 consistent results of four difficulty indices: (1) $p < 30\%$, up to 9 difficulty learning test items, (2) $30\% \leq p < 50\%$, to 9 difficulty towards easy test items, (3) $50\% \leq p < 70\%$, to 1 easy towards difficulty test item, and (4) $70\% \leq p$, to 1 easy test item. The statistical p values marked four demonstrations of difficulty indices: each separate p value was measured difficulty or difficulty towards easy test items of 36.84% and towards as easy or difficulty test items of 13.16%, cumulative scores for test items in students' total conceptual understanding level. All p values exemplified special characteristic functions on students' understanding distributions of difficulty index in 20 test items of HODEI. Students' difficulty indexes of pilot test results were compiled to find homogeneous distributions which would be helpful to detect their learning performances and individual differences.

Table 2
193 Students' answering right rate for HODEI with cognitive levels

Test item	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cognitive Level	A	A	K	K	C	C	A	A	A	A	K	K	K	C	C	K	A	A	A	A
Answer Rate (%)	44	46	11	34	80	21	45	48	32	41	41	32	17	20	25	9	20	51	27	28

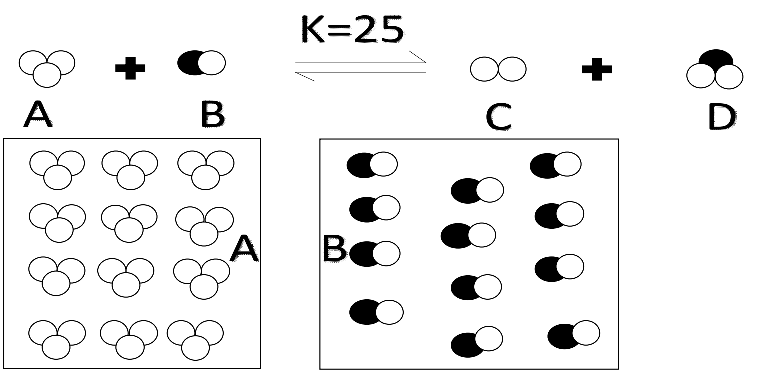
Note: R, Retrieval; C, Comprehension; A, Analysis; K, Knowledge utilization.

In students' answering responses of HOCS options in 20 test items, six senior chemistry professors independently had evaluated the fulfillment for assigning the differentiated validity of HODEI Marzano's cognitive levels. The Kendall's coefficient of concordance (ω) was used to examine the responses of students' statistic agreement by six senior chemistry professors. The research finding ω value 0.669 (χ^2=76.317, p< .001) indicated that the substantial responses of HODEI options in Marzano's cognitive levels were on the agreeable affiliation by six senior chemistry professors. The exact analyses of inter-rater reliability opened up the statistic coefficient ω between .6~.8 which was developed to be consistent agreement (Marozzi, 2014). Therefore, the HODEI included a set of 20 test items which were published at Chinese Internet station assigned to estimate college students' Marzano's cognitive understanding level (web address: https://goo.gl/forms/64aipoNQnMFGnP1F3).

Students' Answering Rate

Figure 3
Summary of HODEI Instrument in No. 16 Test Item

16. In a closed vessel, put into equal amount of the gas particulate matter A and B respectively, just as the following figure, when the gas particulate matter A and B were mixed in producing the equilibrium equation as follows: $A_{(g)} + B_{(g)} \rightleftharpoons C_{(g)} + D_{(g)}$ K=25. Which of the following particulate matter C and D in chemistry equilibrium will be the correct choice item?



(A) 5 · 5 (B) 8 · 8 (C) 9 · 9 (D) 10 · 10.

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One more demonstrated example for No. 16 test item was shown in Figure 3 as one of correct choices in HODEI options. As shown from the summary of HODEI instrument for No. 16 test item in Figure 3, Marzano's higher-order cognitive test item indicated the simple chemistry equilibrium descriptions of two gas particulate reactants of A and B to produce gas

products of C and D. As the process went on, the equilibrium reaction $A_{(g)} + B_{(g)} \rightleftharpoons C_{(g)} + D_{(g)}$, the equilibrium-constant expression was K= [C][D]/[B][A]. The aforementioned 20 test items provided a well-designed and profound understanding of learning for students to take active participation in HODEI options for guidance. Students could identify their own subsequent test items to develop from the Marzano's hierarchical cognitive understanding.

In students' response to the research question 3, their answering right rates for assessment instrument were demonstrated in Table 3. All 133 students' learning performance followed the proportions of 4 main Marzano distribution levels in hierarchical cognitive understanding. Students' comprehensive extent of HODEI with cognitive levels was described in the following ways: students with the knowledge utilization level (L4) had 6 test items and their average answering rate 27.3%; students with the analysis level (L3) had 10 test items and their average answering rate 38.0%; students with the comprehension level (L2) had 4 test items and their average answering rate 25.8%, and students with the retrieval level (L1) got 0 test item in Table 3.

Table 3

133 Students' Answering Right Rate with Cognitive Levels in Marzano's Spectrum

Test item	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cognitive Level	A	A	K	K	C	C	A	A	A	A	K	K	K	C	C	K	A	A	A	A
Answer Rate (%)	49	38	17	34	51	12	46	41	35	42	51	32	15	22	18	15	21	50	29	29

For further developments of their evaluation results, students should have complete command of two higher-order Marzano's cognitive levels (L3 and L4). Students with the analysis level (L3) could concretely describe their expectations, explain reasons in generalizing, analyzing, classifying to find out any learning performances which could be matching to extend chemical equilibrium concept knowledge. For more intermediate students with the knowledge utilization level (L4), they could investigate, experiment, solve problems and make decisions in creating a new understanding and cleared knowledge for more explanations to articulate authentic tasks of chemistry delivery and up to so called the Marzano's higher-order cognitive level. Subsequently, both two higher-order cognitive levels (L3 and L4) contributed a differentiated rated proportion of 55.3% higher-order cognitive skills, in contrast with the above description of students' low-order comprehensive level 25.8% (shown in Table 4). Accordingly, both students' two higher-order Marzano's cognitive levels (L3 and L4) were in accordance with the HODEI of cognitive levels as a HOCS-center hierarchical understanding.

Students' Particle Distributions of Cognitive Levels

With macroscopic, symbol and micro characteristic presentations, students' three particle distributions were summarized in Table 5. The principal classifications for students' two different levels were assessed in their assembled characteristic particles of macroscopic, symbol and micro presentations in the Marzano spectrum. For students with higher-order thinking level, the array of their six test items were distributed in accordance with three distributions of particle characteristics. As suggested by results of HODEI, there were ten test items for students' different distributed indications of the same thinking level in accordance with two presentations of symbol and micro characteristic particles. For students with lower-order thinking level, the array of their four test items were distributed in accordance with only two presentations of macroscopic and symbol characteristic particles.

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Table 4
133 Students' Average Answering Right Rate (%) for HODEI with Cognitive Levels

Cognitive Level	LOCS		HOCS	
	R	C	A	K
Average answering right rate	0	25.8	38	27.3

The total compilation of students' three distributions of particle characteristics presented the following HODEI proportion: 50% test items with macroscopic particles, 100% test items with symbol particles, 80% test items with micro particles. From the above results, students equipped with a good command of macroscopic, symbol and micro particles would have a close link with the construction of HOCS-centered learning as the suggestions of Treagust et al. (2003) for comprehensive chemistry problem-solving (Su, 2017; Toledo & Dubs, 2016).

Table 5
The Test Items Distribution of the Macro, Micro, and Symbolic Levels in Chemistry

Test item	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cognitive Level	A	A	K	K	C	C	A	A	A	A	K	K	K	C	C	K	A	A	A	A
Macro	V	V	V	V	V	V								V	V		V		V	
Symbolic	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V
Micro	V	V	V	V	▯	▯	V	V	V	V	V	V	V	▯	▯	V	V	V	V	V

Discussion

Students' validation of HODEI test items was in accordance with the finding of six senior chemistry professors to present expert content validity and inter-rater reliability specifically. Most important of all, Marozzi (2014) proposed four agreements for Kendall's coefficient of concordance of inter-rater reliability, in its functional relationship with the application of this methodology. In this research, the HODEI test items served as an effective instrument with consistent agreement for functional reliability and expert validity. It was scholarly agreement that the consistent agreement required students' subsequent self-development of HOCS-centered learning for the HODEI understanding with Marzano spectrum (Toledo & Dubas, 2016). Furthermore, research studies with the cognitive hierarchical HODEI test items would clarify students' four understanding tasks starting from lower-order cognitive levels (retrieval task and comprehension task) to higher-order cognitive levels (analysis task and knowledge utilization task) in Marzano spectrum.

Students' engagement of answering right rates was generally assigned as an active response of HODEI test items in Table 4. They could achieve average answering right rate both for 55.3% students with higher-order cognitive skill and 25.8% students with lower-order cognitive skill in this research. It provided a new evaluation and assessment for college students to focus on their research-based development of Marzano's spectrum within chemistry learning. Within contemporary reforms of chemistry teaching, scholars emphasized an existing consensus for students' acquisition of HOCS to constitute a dynamic instructional goal (Toledo & Dubas, 2016; Zoller & Pushkin, 2007). Ghani et al. (2017) pointed that the HOCS development of educational transformation in the 21st century has promoted students' in-depth knowledge understanding in science learning. Seen as an important functional indication, students' HOCS-oriented achievement should go hand in hand with HOCS chemistry teaching goals to promote more students' constructive and transferable knowledge.

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Reaching their engagement upon three distributions of particle characteristics, students were available for their presentations of 50% test items with macroscopic particles, 100% test items with symbol particles, 80% test items with micro particles. This research offered an effective functional way to distinguish particle distributions of lower and higher-order cognitive levels in Marzano's taxonomy which could promote students develop these skill tasks gradually as proposed by Toledo and Dubas (2016). In addition to the finding by Jaber and BouJaoude (2012) for macro–micro–symbolic teaching in promoting students' latent conceptual understanding and relational learning of chemical reactions, the claims for thermodynamic properties by Becker et al. (2013) served as an alternative justification of students' particulate-level of understanding physical and chemical properties. The improvement of Su's (2020) proposal for micro and symbolic performances also animated students' cognitive skills and advanced their hierarchical understanding in chemistry equilibrium classroom.

The application of Marzano's Taxonomy with HOCS-oriented learning testified a special perspective to assess students' higher-order thinking abilities in chemistry learning. The required achievements of Marzano's four cognitive levels were different from those of Bloom's revised taxonomy in educational objectives (Anderson & Krathwohl, 2001; Marzano & Kendall, 2007). As Bransford et al. (2004) suggested that HOCS-oriented learning was essential in transferring more easily students' authentic knowledge across chemistry courses and to apply science to new situations, the combination of instructive situations and strategies by Zoller and Pushkin (2007) made an advanced appeal for students' implementation of higher-order cognitive skills step by step.

As an important foundation of students' STEM, chemistry was inseparable from new problems which scholars encountered in clinching aggressively with Marzano's HOCS-oriented learning (Eichler& Peeples, 2016; Norris & Philips, 2012). The major hierarchical spectrum of Marzano's taxonomy was constructed in four classifications from retrieval, comprehension, analysis to knowledge utilization as a functional method to distinguish lower-order from higher-order thinking abilities (Toledo & Dubas, 2016). The innovated analyses of Marzano's taxonomy were much different from those of simple three-tier diagnostic instrument and order multiple choice items in traditional teaching assessments (Su, 2019). The most successful target of Marzano's taxonomy would be associated with students' experience and participation in a new coalition of higher-order thinking abilities systematically.

Conclusions

The final results of this research proposed a well-prepared development for students' participations in Marzano's hierarchical spectrum and their unification in higher-order thinking competence. Through the step by step composed learning of Marzano's taxonomy, students succeeded in constructing higher-order thinking abilities related to HOCS-oriented and Marzano's brain-based learning for the particle nature of matter in chemistry equilibrium. In regard to students' particle distribution, it also became important to take into account their answering rates, as well as the academic alignment of positive affect. Students' engagement of hierarchical understanding originated from their comprehensive participation in chemistry classes and to the fra mework of long-term STEM in Marzano's spectrum.

This research would inspire students to make more frequent cognitive participation activities shifting from comprehensive analysis to knowledge utilization in contrast with most traditional chemistry learning. Students would strengthen their hierarchical development and multiple interactive engagements with HOCS-oriented activities of Marzano's brain-based learning for promoting more constructive thinking elements of HOCS chemistry abilities. In accordance with scholars' requirements for thinking processes of high-achieving programs, this research offered a new HOCS-centered perspective for students' cognitive participation and the future design of academic resources and suggestions in chemistry classroom.

On the top finding of that statement, despite not aimed at discussing chemical particulate nature of matter regarding students' learning progress individually, the Marzano's HOCS-oriented learning was expected to be beneficial and advantageous for students' additional learning efficiency. More suggestive instructions for students' HOCS-centered perspective of both analysis and knowledge utilization tasks in Marzano's spectrum would be responsive consideration to instructors' teaching, professional development, and future research.

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