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ANALYTIC APPROACH OF RESPONSE PATTERN OF DIAGNOSTIC TEST ITEMS IN EVALUATING STUDENTS' CONCEPTUAL UNDERSTANDING OF CHARACTERISTICS OF PARTICLE OF MATTER

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Bambang Sumintono,
Mohamad Jahja,
Citra Panigoro

Abstract. *This research aimed to evaluate the students' conceptual understanding and to diagnose the students' preconceptions in elaborating the particle characteristics of matter by development of diagnostic instrument as well as Rasch model response pattern analysis approach. Data were acquired by 25 multiple-choice written test items distributed to 987 students in North Sulawesi, Indonesia. Analysis on diagnostic test items response pattern was conducted in three steps: 1) conversion of raw score to a homogenous interval unit and effectiveness analysis of measurement instruments; 2) measurement of disparity of students' conceptual understanding; and 3) diagnosis of students' preconception by estimation of item response pattern. The result generated information on the diagnostic and summative measurement on students' conceptual understanding in elaborating the topic; information also acts as empirical evidence on the measurement's reliability and validity. Moreover, the result discovered a significant disparity between students' conceptual understanding based on their educational level. It was found that the distractor item response pattern tended to be consistent, indicating a certain tendency of resistant preconception pattern. The findings are expected to be a recommendation for future researchers and educational practitioners that integrate diagnostic and summative measurement with Rasch model in evaluating conceptual understanding and diagnosing misconception.*
Keywords: *conceptual understanding, item response, particle of matter, Rasch model*

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Introduction

Central to the notion of learning about characteristics of a particle of matter is the process of developing an understanding on abstract concepts (Johnstone, 1991) without directly interacting with the object/fact (Stojanovska et al., 2012); therefore it is considered a difficult subject for the students to learn. Echoing this, the disparity in understanding is almost inevitable (Kapici & Akcay, 2016) since different students may develop their own distinctive way of understanding a concept (Yildirir & Demirkol, 2018). The idea is also coined by experts as misconception (Johnstone, 2006, 2010; Taber, 2015), or alternative framework and preconception (Lu & Bi, 2016). The experts have discovered that students always have their own preconception that is not in line with scientific concepts (Alamina & Etokeren, 2018; Yaşar et al., 2014); therefore, one needs to conduct identification and improvement on the conceptual learning (Allen, 2014; Soeharto et al., 2019).

In diagnosing preconceptions, several researchers have developed diagnostic instruments in different mechanisms (McClary & Bretz, 2012), i.e., conceptual map, essay test, interview, essay test with interview, or multiple-choice test (Femintasari et al., 2015). Two-step multiple choice diagnostic test (Adadan & Savasci, 2012; Chandrasegaran et al., 2007; Treagust, 1988; Tüysüz, 2009) is preferred due to its ability to diagnose preconception and describe the underlying reasons. The instrument is indeed considered qualitatively effective in elaborating differences in students' thought processes; however, it does not provide summative measurement features due to lack of internal consistency and the instrument's unidimensionality (Lu & Bi, 2016). In addition to that, the measurement conclusion generated is considered weak due to extracted from analysis on the raw score (Sumintono, 2018)

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Studies on preconception have found that the concept is somewhat resistant. In the early 2000s, it is discovered that students' preconceptions persisted even when they already undergo formal education experience (Hoe & Subramaniam, 2016). Preconception can also change along with the development of students' conceptual understanding; it also varies in different levels of understanding (Aktan, 2013). If one conducts a two-step test and raw score analysis approach to diagnose resistant preconception, the result generated will only provide limited feedback information (Sumintono, 2018) due to the instrument's limitation in measuring students' conceptual understanding. Instead of supporting, the information will only make it harder for teachers to implement proper instructional decisions (Wilson, 2008).

During the middle of the 2000s, the Rasch model analysis was commonly used in studies of chemistry education (Herrmann-Abell & DeBoer, 2011; Liu, 2012; Wein et al., 2012). The approach provides a testing apparatus that integrates diagnostic and summative measurement. Recently, this approach is used to develop formative assessment with the intention to conduct learning construction mapping, e.g., measuring the students' way of constructing their understanding process (Hadenfeldt et al., 2013). It is worth to note, however, that there are studies that integrate diagnostic and summative measurement with a different approach (Hoe & Subramaniam, 2016); despite that, trends in chemistry education studies highlight that diagnostic-summative measurement by Rasch model analysis is more common to be carried out (Laliyo et al., 2019; Lu & Bi, 2016).

Research Problem

The characteristics of a particle of matter is a fundamental concept in chemistry, usually taught in middle education level. Adequate comprehension regarding the particle characteristics of matter both in macroscopic and microscopic level is essential as the knowledge basis in understanding more advanced topics such as the concept of atoms and molecules as the submicroscopic component that is invisible to plain eyesight but exists in all real-world phenomena (Cheng, 2018; Ozmen, 2011; Yildirir & Demirkol, 2018). The fact signifies the relevance and reasoning of complexity in chemistry learning that is considered difficult for both students and teachers to conduct (Alamina & Etokeren, 2018). In simpler terms, to ensure that the chemistry learning is conducted effectively, one requires to nurture students' comprehensive understanding regarding particle characteristics of matter and its change of state.

To evaluate the students' conceptual understanding on the aforementioned topic, one also needs to measure the students' capability in interpreting particle state during change process of a matter's form (Alamina & Etokeren, 2018; Barbera, 2013; Boz, 2006; Cheng, 2018; Gabel, 1993; Hadenfeldt et al., 2013; Kapici & Akcay, 2016; Kind, 2004; Naah & Sanger, 2012; Ozalp & Kahvecib, 2015; Ozmen, 2011; Renström et al., 1990; Slapničar et al., 2017; Stojanovska et al., 2012; Yildirir & Demirkol, 2018). Research studies on particle characteristics and changes of matter generally employ diagnostic instruments in the form of essay tests and/or essays followed by interview; the instruments are further analyzed based on raw score results. The approach is considered inefficient and somewhat lacked accuracy in measuring students' conceptual understanding and misconception pattern. Despite its ineffectiveness, the conventional method is used by most teachers in Indonesia to measure and determine students' learning progress. The teachers argue that measuring the students' raw score is effective in determining how far the students have progressed in the learning process. The students' raw score is regarded by many as an early premature indication regarding the measured variable and is not eligible to be the final measurement indicator due to its temporary nature. In addition to that, regarding the decision-making process, the raw score contains only limited information for it to be treated as reference (He et al., 2016; Sumintono & Widhiarso, 2015)

Research Focus

The research focuses on developing a diagnostic instrument that integrates measurement of conceptual understanding and diagnosis of students' preconceptions regarding the aforementioned topic by the approach of Rasch model item response pattern analysis. The analysis employs different test apparatuses to provide extensive information for practitioners and researchers in science education in evaluating students' learning progress in different topics.

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Research Questions

This research aimed to figure out the following questions: 1) How is the effectiveness of measurement instrument to evaluate the students' conceptual understanding and diagnose their preconceptions on the characteristics of a particle of matter? 2) Is there any significant difference between students in elaborating on the aforementioned topic based on their educational level? 3) How is the pattern of students' conceptual understanding and preconception regarding the topic?

Research Methodology

General Background

The descriptive-quantitative research employed a non-experimental approach, in which the students' conceptual understanding in explaining the characteristics of a particle of matter was treated as the measurable variable. Prior to conducting the research, it was ensured that the students already experience formal learning of the aforementioned topic. The researchers did not conduct any intervention on the learning process or the learning material. In other words, no treatment was implemented to the students for them to be able to answer all test items in the measurement instrument.

The data collection step was implemented for four months in the even semester of the 2019-2020 academic year; the process was conducted after obtaining approval from the Government of Province of Gorontalo and heads of universities in the Northern part of Sulawesi, Indonesia. Moreover, the schools' and parents' approval was obtained in cooperation with the school committee. The school administrators were willing to facilitate the data collection process that adjusted with the schedule.

Respondents

The respondents were 987 people consisting of students of eleventh grade from eight lower-secondary schools well as university students of the chemistry department in Northern Sulawesi, Indonesia. The distribution of respondents is displayed in Table 1 below.

Table 1
Demographic profile of respondents (N=947)

Demography	Code	Respondents	Percentage (%)
Gender			
Male	M	320	67.68
Female	F	667	32.42
Education level			
X Class students	M	168	17.02
XI Class students	N	473	47.92
XII Class students	O	186	18.84
University students from the chemistry department	P	160	16.21

The respondents were chosen randomly and have voluntarily agreed to participate in the research. In addition, they received no learning treatment and other special treatments that allow them to complete the measurement instrument. Students were asked to write down their responses in the answer sheet; the process was supervised by teachers in the respective schools and lecturers in the respective university. All students were instructed to answer all questions in the instruments within 45 minutes. All instrument sheets and answer sheets were collected by the researchers shortly after the session ended; it was ensured that the numbers of instruments matched the numbers of participants. For the certainty in ethical consideration, permission was obtained from the school administration after coordinating with students' parents through the school committee. This process was conducted before the

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students were invited to participate in research. Permission for the students was obtained from the department leaders of the university, and student written statements. All students were told that the confidentiality of their identity was fully guaranteed, and the results of the study would only be used for research purposes.

Instrument and Procedures Development

The design process refers to a recommendation by Wilson (2005), which consists of four key steps: definition of construct map, item design, result blank, and measurement model.

Phase 1: Definition of construct map. The map offers a substantive definition of measured constructs; the more constructs measured, the constructs' level will vary qualitatively (Wilson, 2009). In simpler words, it aims to develop the students' understanding map to measure the students' progress (Wilson, 2012). The instrument involved variables, i.e., the students conceptual understanding and preconception in elaborating the characteristics of a particle of matter; it was conducted in accordance with the Curriculum Standard of Chemistry Subject in Tenth Grade in Indonesia, as presented in Table 2.

Table 2
Conceptual Understanding Level

Level 3	**The students are able to connect between characteristics of a particle of matter in macroscopic and submicroscopic level**
Phenomenon	Evaporation: item Q6/Bubble
10. Preconception	Air bubble consists of Hydrogen and Oxygen particles
9. Preconception	Air bubble is water-soluble
Phenomenon	Condensation: item Q5/Dew
8. Preconception	Water drops come from melting ice that penetrates the glass wall
7. Preconception	Water drops are the result of the reaction between ice and air nearby the glass
Level 2	**The students are able to determine SMRs diagram of particle structure during a change of form: item Q11/SMRs/SL; Q12/SMRs/LG; Q13/SMRs/GS; Q25/SMRs/GG**
6. Preconception	The SMRs diagram of particle structure follows the physical form of matter
5. Preconception	The SMRs diagram of O2 molecule shape undergoes change as a result of an increase in the volume of the container.
Level 1	**The students are able to determine the characteristics of a particle of matter during the change process of matter's form.**
4. Preconception	The particle size of matter changes into (large/small) as a result of change in matter form: item Q1/PS/SL; Q7/PS/LG; Q14/PS/LG; Q18/PS/SG; Q22/PS/GG
3. Preconception	The particle mass of matter changes into (large/small) due to change in matter form: item Q2/PM/SL; Q8/PM/LG; Q15/PM/LG; Q19/PM/SG; Q24/PM/GG
2. Preconception	Distance between matter particles changes into (faster/slower) due to change in matter form: item Q3/DP/SL; Q9/DP/SL; Q16/DP/LG; Q20/DP/SG; Q23/PM/GG
1. Preconception	Motion between matter particles changes into (dense/loose) due to change in matter form: item item Q4/PMo/SL; Q10/PMo/LG; Q17/PMo/LG; Q21/PMo/SG

Variation in conceptual understanding level illustrates the development process of the students' conceptual understanding. In the first level, the students were asked to determine particle characteristics (size, mass, motion, and distance) in the change process of matter form. In the second level, the students were asked to determine the submicroscopic representation diagram of particle structure. Further, in the third level, the students were asked to connect between characteristics of a particle of matter at the macroscopic and submicroscopic level. In each level, the construct map also features the students' tendency of preconception.

Phase 2: item design and evaluation The phase involved the determination process of items to be used in acquiring evidence of students' construct understanding regarding the construct map (Wilson, 2005). Certain items may have a different extent of effectiveness to measure students' conceptual understanding (Sadler, 1999);

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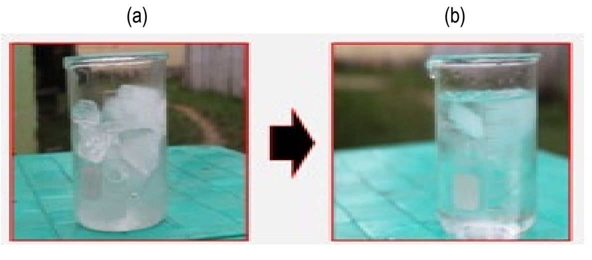
however, multiple choices item is considered more practical and effective (Wilson, 2008). The instrument of concept understanding test of the particle (or TPKP) is adapted from multiple-choice instruments by (Herrmann-Abell & DeBoer, 2011). Each item consists of two distractor answer choices and one open answer choice. The distractor answer choices are designed by referring to the common preconceptions by the students (see Table 2) as logical choices to distract the students from the correct one. The distractors function to emphasize the item diagnostic strength (Sadler, 1998). Some of the items are adopted from previous studies Osborne & Cosgrove (1983), Renström et al., (1990); Devetak et al., (2004); Tóth & Kiss (2006); Davidowitz et al., (2010); Devetak & Glažar (2010); Slapničar et al., (2017) and (Yildirir & Demirkol, 2018).

Figure 1
Sample of item Q1/PS/SL design



Glass (a) contains ice chunks; glass (b) contains melting ice chunks. How is the size of water particle in solid form (ice) compared to that in liquid form?

a. Size of a water particle in solid form > a water particle in liquid form.
b. Size of a water particle in solid form < a water particle in liquid form.
c. Size of a water particle in solid form = a water particle in liquid form.
d. Other answers

Figure 1 displays a sample of item Q1/PS/SL design, in which Q1 is the number of item 1, PS is particle size, and SL is solid-liquid. The item measures student's capability in determining particle size in form change from solid to liquid. The choice A and B are distractors, the correct choice is C, and choice D is for other answers students may fill if the existing answer choices are not in accordance with their initial knowledge. Every correct answer was given mark 1, and wrong answers got 0 mark. Each student only has a slight probability of 0.25 in choosing the right answer. The students will pick what they think the right answer based on their understanding. If the distractor item choice functions well, the students will not be able to predict the correct answer.

Phase 3: design of result blank, i.e., the correlation between construct map and items (Wilson, 2005). This phase aimed to identify whether the answer the students pick correlates with their conceptual understanding; in simpler terms, it was intended to elaborate the conformity between the variable contents being measured. In order to elaborate on the previous aspect, the TPKP instrument was validated by three independent experts and tested to the students to acquire their feedback. The process acquired 25 items of TPKP. Prior to the data collection process, it was ensured that all students had received formal education on the characteristics of a particle of matter and its changes. The students' response towards the instrument was inputted manually by the written answer sheet. The test was supervised by the teachers in school by referring to the agreed permission and duration. Each student was required to finish all test items within the allocated duration of 45 minutes. The instrument sheets were further collected, and checking process was conducted to ensure that the amount of instrument sheet was the same with participating students.

Phase 4: Rasch model analysis approach. The analysis integrates algorithm as a result of probabilistic expectation of item 'i' and student 'n', as: The statement is the probability of student n in item i to result in the correct answer (x = 1); with student ability, ßn, and item difficulty level (Bond & Fox, 2015). The above equation was simplified by inserting logarithm function, into, so that the probability of picking the right answer equals to student's ability subtracted by item difficulty level. The student (person) and item units were considered on the same interval scale and were independent of each other. The students' ability level and item difficulty level were measured in the logarithm unit, namely odds or log that variates from -00 to +00 (Herrmann-Abell & DeBoer, 2011; Sumintono & Widhiarso, 2015). The instrument efficiency, when compared to the item distribution towards item difficult level with distribution of student's ability level, was quantifiable in order to measure the students' conceptual understanding. In addition, the student's understanding level was differentiated based on the item size. The previous steps highlighted the main difference of Rasch model analysis when compared to the raw score-based conventional one; the latter lacks accuracy in evaluating students' ability observed from different item difficulty level (Herrmann-Abell & DeBoer, 2011; Lu & Bi, 2016; Sumintono & Widhiarso, 2015).

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Data Analysis

The research employed WINSTEPS version 3.75 software to convert raw data into interval data (Bond & Fox, 2015; Linacre, 2012). The conversion result acted as the calibration of data on the student's ability level and item difficulty level within the same interval measurement. Moreover, the analysis on diagnostic test items response pattern was conducted in three steps: 1) conversion of raw score to a homogenous interval unit and effectiveness analysis of measurement instruments; 2) measurement of disparity of students' conceptual understanding by Differential Item Functioning (DIF) item test; and 3) diagnosis of students' preconception by estimation of item response pattern through option probability curve test.

Research Results

Effectiveness of Measuring Instruments

Person and Item Reliability. The first step to elaborate on the effectiveness of measuring instruments was by measuring the person and item reliability. This was conducted to gather information to what extent the measurement produces consistent information in displaying latent trait or the unidimensionality of the measured variable (Sumintono & Widhiarso, 2015). The analysis result is presented in the form of a statistical summary (Table 3).

Table 3
Summary of fit statistics

Parameter (*N*)	Measure	INFIT		OUTFIT		Separation	Reliability	*SD*	KR-20
		MNSQ	ZSTD	MNSQ	ZSTD				
Person (987)	-.34	1.00	-.11	1.02	-.1	1.55	.71	.88	.72
Items (25)	.00	1.00	-.75	1.02	-.1	8.18	.99	.60	

The above table indicates that the person reliability value of 0.71 is equivalent to the person separation index value of 1.55. This is to say that the consistency of students' response towards the test is deemed good. In addition to that, it is generated that the *Cronbach Alpha Coefficient* (KR-20) value is 0.72, signifying good interaction between students and the test. This further indicates strong correlation between the students' response towards the item, in the context that the students' knowledge tends to be non-fragmented, enabling it to be measured (Adams & Wieman, 2011). To the researchers and educational practitioners, such information is essential to prepare for follow-up plans and development of students' ability (Wei et al., 2012). Moreover, the result generated a relatively high value of item separation index of 8.18 that was equivalent to the item reliability value of 0.99. This indicated very good item consistency, or the item was deemed capable of meeting the unidimensionality criteria. In other words, the item performed very good in defining the measured variable. This was confirmed by the infit and outfit value result, in which most of the items were in the acceptable range for the multiple-choice test (Bond & Fox, 2015; Herrmann-Abell & DeBoer, 2011).

Figure 2 displays the graph of measurement information in order to show the measurement reliability. The higher the tip of information function graph, the measurement reliability value is likely to increase. In the intermediate level of students' ability (-3.0 logit up to +3.0 logit), the measurement information is in very high spot. This indicates that the TPKP instrument is capable of producing optimal information to students with an intermediate level of ability. Such a result means that the instrument possesses high measurement reliability (Bond & Fox, 2015; Kim & Wilson, 2019).

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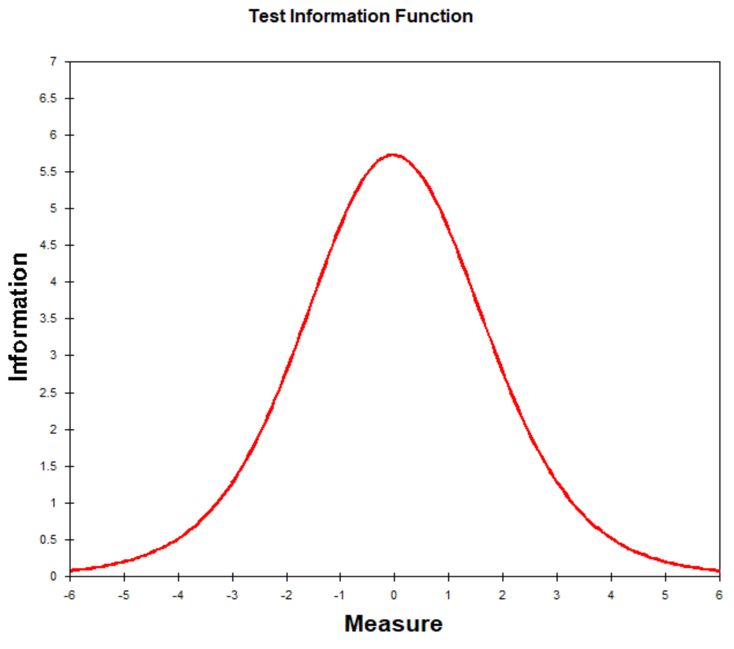
Figure 2
Function of Measurement Information



Note: M = X Class students, *N* = XI Class students, O = XII Class students, and P = University students from chemistry department

Validity. The next step was to measure the item validity by Fit item test to ensure that all items fit with the Rasch model. The process was aimed to identify whether or not the test item could measure the aspects that intended to be measured, or test validity (Linacre, 2012; Sumintono & Widhiarso, 2014). The criteria used comprise outfit means-square (MNSQ): 0.5 < y < 1.5; outfit z-standard: -2.0 < Z < + 2.0, as well as point measure correlation (PTMEA Corr). The PTMEA Corr is the correlation between the score of item and person measure that is required to be a positive value and not approaching zero (Bond & Fox, 2015). The PTMEA Corr criteria: 0.4 < x < 0.8. If all three criteria are not met, the item is not good enough and needs further elaboration (Boone et al., 2014). Both Outfit MNSQ and Infit MNSQ were sensitive chi-squares in detecting outlier response pattern. There were two outlier responses: the right response, guessed by the students with low ability in item with high difficulty level, or the wrong response due to the high-ability students' carelessness in items with a low difficulty level. The expected ideal MNSQ value is 1.0. The analysis result on item appropriateness is displayed in Table 4 as follows:

Table 4
Item Statistics: Misfit Order

Item	Measure	INFIT		OUTFIT		PTMEA Corr
		MNSQ	ZSTD	MNSQ	ZSTD	
Q6/Bubble	.60	1.26	7.0	1.40	7.5	.07
Q2/PM/SL	.88	1.16	3.7	1.27	4.4	.18
Q15/PM/LG	.66	1.12	3.3	1.20	3.8	.22
Q14/PS/LG	.97	1.03	.8	1.18	2.8	.20
Q18/PS/SG	.71	1.07	1.8	1.15	2.9	.28
Q5/Dew	-.63	1.06	2.6	1.15	3.7	.27

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Item	Measure	INFIT		OUTFIT		PTMEA Corr
		MNSQ	ZSTD	MNSQ	ZSTD	
Q7/PS/LG	.66	1.06	1.6	1.14	2.8	.29
Q8/PM/LG	.65	1.07	2.0	1.11	2.1	.28
Q1/PS/SL	.79	1.00	-.1	1.06	1.1	.35
Q24/PM/GG	.25	1.04	1.4	1.04	1.1	.33
Q19/PM/SG	.77	-.3	1.03	.6	.36	.36
Q3/DP/SL	-.44	1.01	.5	1.00	-.1	.34
Q10/PMo/LG	-.07	.98	-.8	.98	-.5	.38
Q13/SMRs/GS	-.24	.98	-1.1	.98	-.6	.38
Q9/DP/LG	-.32	.97	-1.6	.95	-1.6	.39
Q4/PMo/SL	-.66	.96	-2.0	.93	-1.8	.39
Q25/SMRs/GG	-.68	.94	-2.9	.91	-2.4	.41
Q16/DP/LG	-.47	.94	-3.1	.91	-2.8	.42
Q23/DP/GG	-.44	.92	-3.7	.93	-2.1	.43
Q12/SMRs/LG	-.63	.92	-3.8	.87	-3.5	.44
Q21/PMo/SG	-.66	.92	-4.0	.89	-2.9	.43
Q17/PMo/LG	-.71	.91	-4.4	.87	-3.5	.44
Q22/PS/GG	-.07	.90	-4.4	.87	-3.9	.47
Q11/SMRs/SL	-.27	.90	-4.9	.87	-4.0	.47
Q20/DP/SG	-.65	.86	-6.6	.83	-4.6	.49

From the previous Item Statistics, it is generated that all items meet the Outfit MNSA criteria and no negative PTMEA Corr occurs. This means that all items are not deviant, appropriate, and valid. Despite some items do not meet one of the criteria, this by no means decreases the quality of the items. For instance, item (Q6/Bubble, Q2/PM/SL, and Q15/PM/LG) do not meet the criteria of Outfit *Z* Standard and PTMEA Corr; item (Q1/PS/SL, Q24/PM/GG and Q19/PM/SG) do not meet the criteria of PTMEA Corr; and item (Q25/SMRs/GG, Q16/DP/LG, and Q23/DP/GG) do not meet the criteria of Outfit ZSTD; this is supposedly caused by large size of sample, or *N* > 500 (Boone et al., 2014).

Wright Map: Person-Map-Item. The third step was to measure the consistency of item difficulty level and student's ability test constructed in Table 2. The higher the item difficulty level, the higher also the student's ability level will result. Information of Wright Map: Person-Map-Item is displayed in Figure 3. The previous Wright map generates that all instrument items encompass almost all the students' ability. The map generates variance from students with very high ability (> 3.0 logit), to those with very low ability (< -2.0 logit) as well. In addition to that, disparity (in which there is no item that is appropriate with the student's ability) was observed within the interval of -3.0 logit up to -0.5 logit and in the interval of +1.0 logit up to +3.7 logit. This signified that the information generated within the interval range was somewhat limited and required further elaboration. On the other hand, the item difficulty level was mostly located in the interval of -1.0 logit up to +1.0 logit; moreover, the items tended to occur in the same difficulty level. The item Q14/PS/LG was the most difficult item with a logit of +0.97, while item Q17/Pmo/LG was the easiest item with logit of -0.71.

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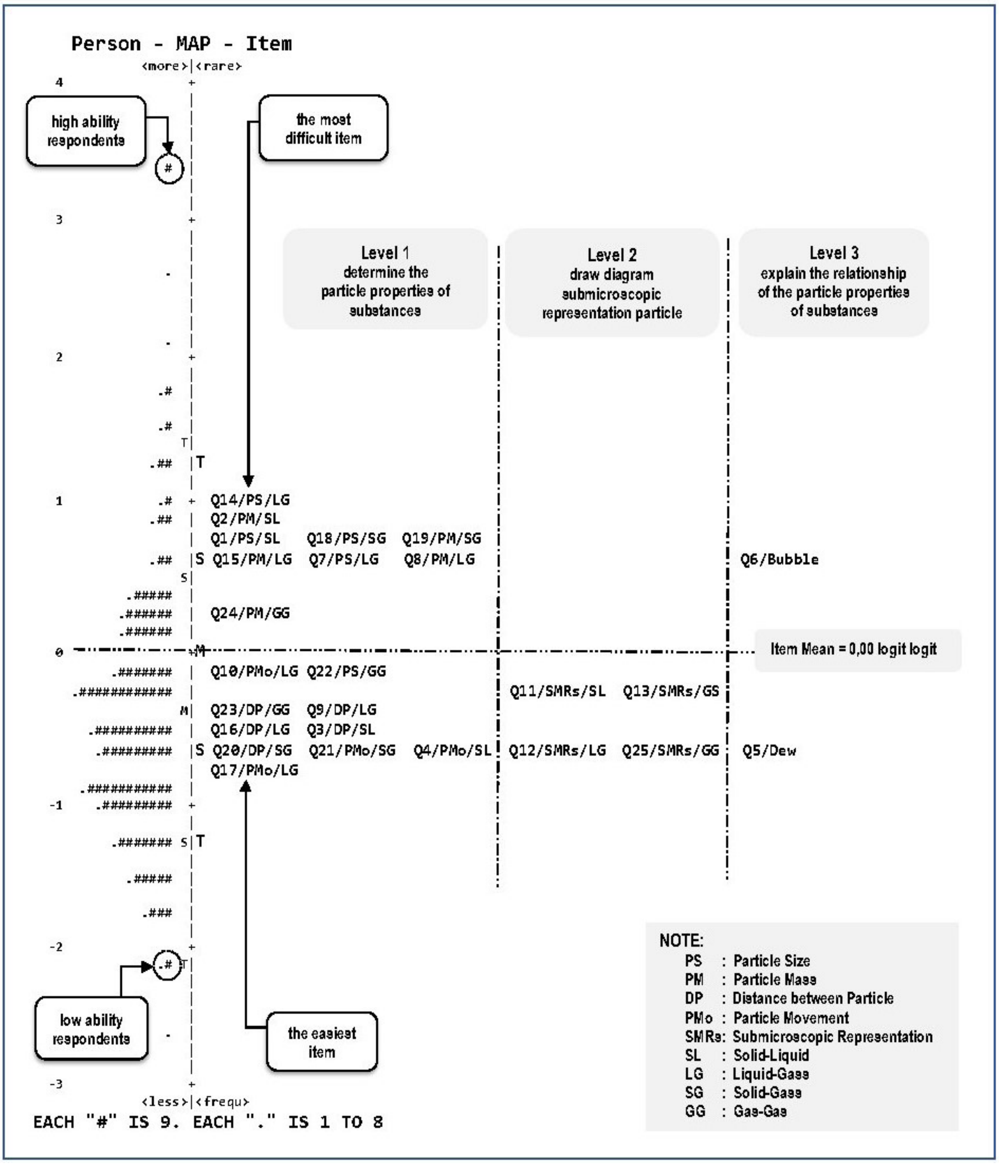
Figure 3
Wright Map: Person-Map-Item



As observed from the differences in item size, some interesting cases were explained as follows: Firstly, the items in level 1: Q14/PS/LG (0.97) > Q1/PS/SL (0.79) > Q18/PS/PG (0.71) > Q7/PS/GG (0.66) were instead assumed by the students to possess different difficulty level. The items above, however, were more difficult than item Q6/Bubble in level 3 (0.60). In other words, determining particle size was more difficult than explaining the particle characteristics of matter in the evaporation phenomenon. Secondly, the size of item Q5/Dew (-0.63) < item Q6/Bubble; this indicated that it was harder for the students to elaborate on the particle characteristics of matter in

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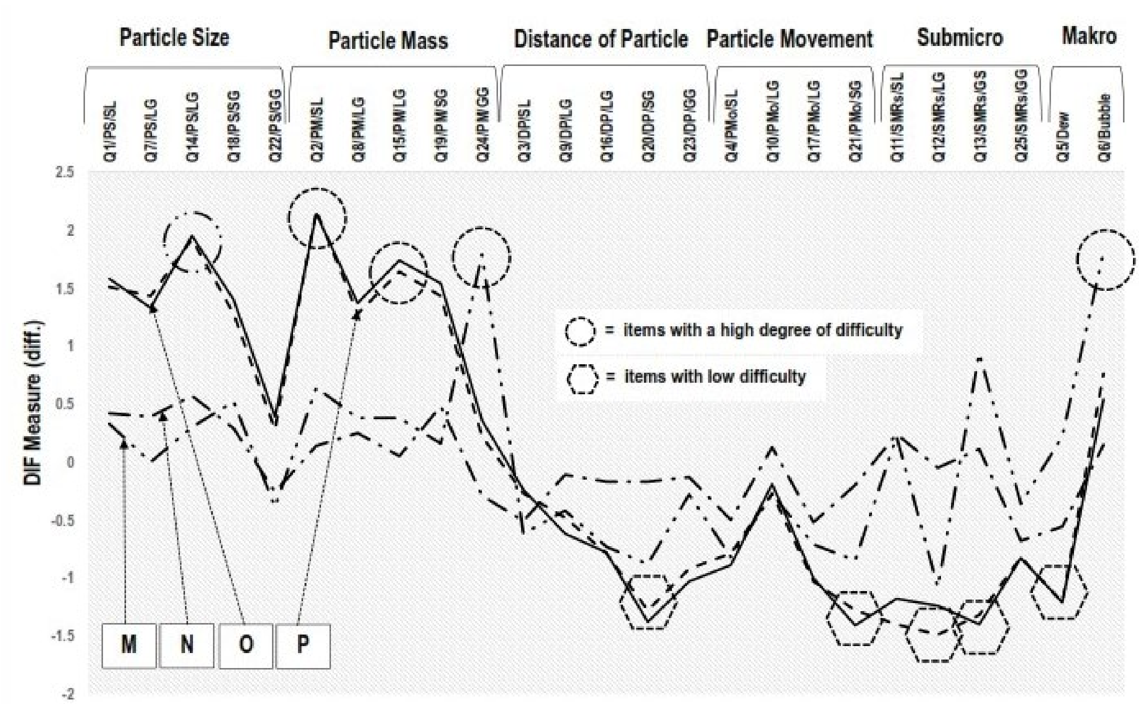
the evaporation phenomenon than in condensation phenomenon, despite that both items were in the same level. Thirdly, the size of following items: Q2/PM/SL (0.88) > Q19/PM/SG (0.77) > Q15/PM/LG (0.66) > Q8/PM/LG (0.65) > Q24/PM/GG in level 1 was larger compared to that of items Q13/SMRs/GS (-0.24) > Q11/SMRs/SL (-0.27) > Q12/SMRs/LG (-0.63) > Q25/SMRs/GG (-0.68) in level 2. The finding illustrated that it was harder for the students to determine the particle mass than determining the submicrorepresentation (SMRs) diagram in different form changes of matter. The previous cases identified disparity in students' conceptual understanding, signifying that the level of understanding in particle characteristics of the matter is relatively low. Overall, 80% of test item difficulty level is relatively parallel with the measured constructs. By that, the test possesses good construct validity (Blanc & Rojas, 2018; Lu & Bi, 2016; Neumann et al., 2011).

Disparity in Conceptual Understanding Level

The next step was the measurement of disparity of students' conceptual understanding in the focused topic based on educational level by Differential Item Functioning (DIF).

Figure 4
Person DIF plot based on educational level



Note: M = X Class students, N = XI Class students, O = XII Class students, and P = University students from chemistry department

Figure 4 of DIF plot based on students' educational level depicts that ten items are identified to possess significant disparity. Firstly, five curves approaching the upper limit are items with a high difficulty level (Q14/PS/LG, Q2/PM/SL, Q15/PM/SG, Q24/PM/GG and Q6/Bubble); while five curves approaching the lower limit are items with a low difficulty level (Q20/DP/SG, Q21/PMo/SG, Q12/SMRs/LG, Q13/SMRs/GS, and Q5/Dew). Secondly, the item Q14/PS/LG (particle size in form change of liquid-gas), Q2/PM/SL (particle mass in form change of solid-liquid), and Q15/PM/SG (particle mass in change form of solid-gas) were deemed very hard by the students of XII class and the university students compared to students in X and XI class. Thirdly, the research discovered different results for item Q24/PM/GG and Q6/Bubble. The item Q24/PM/GG (particle mass of O2 in larger volume) and Q6/Bubble (constructing elements of air bubbles during boiling process of water) were deemed very hard for X class students compared to students in XI and XII classes, as well as university students. Fourthly, the items Q20/DP/SG

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(distance between particles in form change of solid-gas), Q21/PMo/SG (motion between particles in form change of solid-gas), Q12/SMRs/LG (SMRs diagram of particle in form change of liquid-gas), Q13/SMRs/GS (SMRs diagram of particle in change form of gas-liquid), and Q5/Dew (condensation) were deemed too easy for students in XII class and university students compared to the students in X and XI classes.

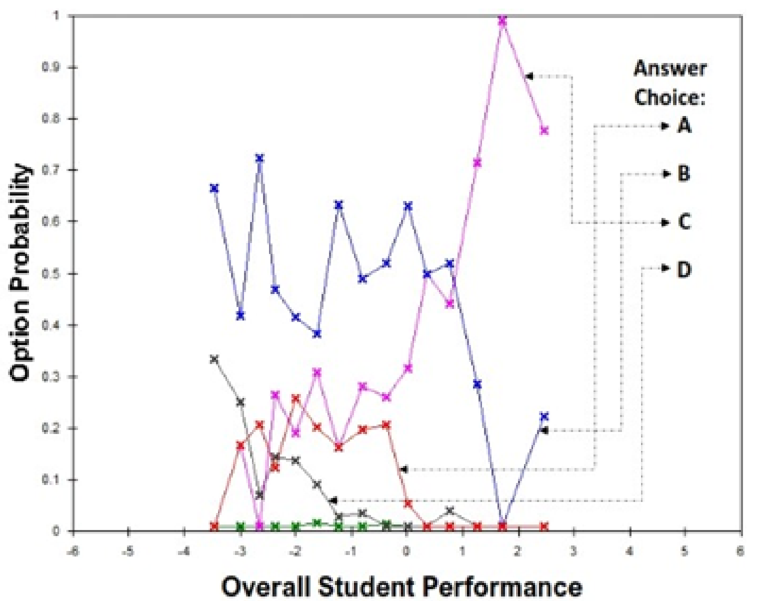
Pattern of Conceptual Understanding and Preconception

The analysis of the pattern of conceptual understanding and preconception employed an option probability curve test (Boone et al., 2014; Linacre, 2012). The option probability curve aims to display the probability of picking every answer choice to elaborate on the performance level of all students in the measured items (Herrmann-Abell & DeBoer, 2011). The test relied on the principle that the curve of the correct answer will rise along with the decrease of the curve of distractor choices (Boone et al., 2014; Haladyna, 2004). For items that are influenced by distractor options, the curve produced tends to be non-parallel with the traditional monotonous item behavior (Sadler, 1998), for this reason, each answer choice was analyzed separately.

The instrument provides four answer choices, thus resulting in four curves. Each curve displays the students' comprehension. Students with low ability tended to pick distractor choice, while students whose high ability were more likely to prefer other preconceptions (Herrmann-Abell & DeBoer, 2011; Perera et al., 2018). Below is the elaboration of the pattern of students' conceptual understanding and preconception based on four option probability curves.

Figure 5
(a) sample of item Q2/PM/SL, (b) option probability curve

(a)
When some ice cubes in the glass melts, some other ice cubes are seen floating on the water surface. How is the comparison between mass of one particle of ice and one particle of water?
A. Mass of one particle of ice is bigger than mass of one particle of water.
B. mass of one particle of ice is smaller than mass of one particle of water.
C. mass of one particle of ice is similar with mass of one particle of water.
D Other answer...

(b)


The first example, i.e., the item Q2/PM/SL (0.88), is shown in Figure 5(a). The item measures students' capability in determining particle size in form change from solid to liquid. The option probability curve is displayed in Figure 5(b). Students with the low ability (< 0.5 logit) tended to pick distractor choice B (mass of one particle of ice is smaller than the mass of one particle of water) or A (mass of one particle of ice is bigger than the mass of one particle of water). In addition, students with very low ability (< -1.0 logit) tended to pick D (other answers). Some students with relatively low ability (> -2.5 logit), however, picked the right answer C (mass of one particle of ice is similar to the mass of one particle of water). One can predict the response pattern of students with low ability, as the distractors A, B, and D contain third preconceptions in level 1 (see Table 2). The students possess the knowledge

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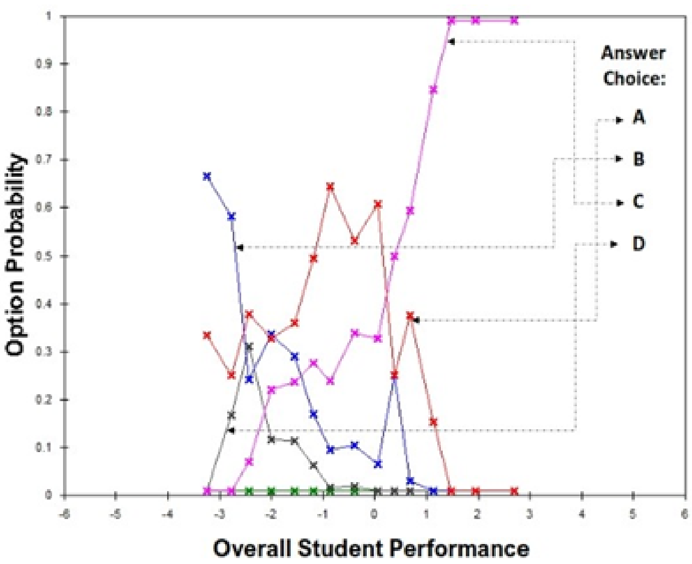
that mass of particle of matter can change into larger or smaller size by observing the matter's change of form. It is interesting to note that there are students with the high ability (>2.0) who picked B; this indicates the presence of resistant preconception.

Figure 6
(a) item Q8/PM/LG; (b) option probability curve

(a)
During boiling process of water, a change of form of water from liquid to gas occurs. How is the comparison between mass of one particle of water and one particle of water vapor?
A. Mass of one water particle is bigger than mass of one vapor particle
B. mass of one water particle is smaller than mass of one vapor particle.
C. mass of one water particle is similar with mass of one vapor particle.
D Other answers...

(b)


The second sample or item Q8/PM/LG (0.65) is shown in figure 6(a) as the item to measure students' ability to determine the mass of the particle in form change of liquid-gas. The option probability curve is displayed in Figure 6(b). The curve of distractor B (mass of one water particle is smaller than the mass of one vapor particle) is chosen by students with low ability (< -2.0 logit), while the curve of choice A (mass of one water particle is bigger than mass of one vapor particle) was chosen by students with ability in a range of -3.5 to 1.5 logit. The correct answer, option C (mass of one water particle is similar to the mass of one vapor particle), was chosen by students with ability in > -2.5 logit. As highlighted in the table, the decline of the curve of distractor A is followed by the increase of curve of right answer C; both curves intersect in the level of 1.0 logit. The shape of curve A indicates the presence of resistant preconception type-three in level 1.

It depicts that the particular item response pattern that signifies students' conceptual understanding patterns in the given level. Moreover, the curve shape of distractors A and B in the items Q2/PM/SL and Q8/PM/SL tend to have an identical pattern. The finding indicated that students with either low or high ability had consistent preconceptions that the mass of the particle can change into larger or smaller in size along with the change in matter form.

Third sample, i.e., item Q5/Dew (-0.63), as shown in Figure 7(a), measures the students' ability in elaborating characteristics of a particle in condensation phenomenon. The option probability curve is displayed in Figure 7(b). Students with low ability (< 1.0 logit) tended to pick distractor A (water drops come from liquid of melting ice that breaks through the glass wall) and option D (other answers). Some students with high ability (> 1.0 logit) also picked distractor B (water drops are the result of the reaction between ice and air nearby the glass). The shape of curve B is wavy and non-linear, even in the interval of 2.0 to 4.0 logit, it can reach option probability value up to 1.0 logit. This is regarded as a deviation from the right answer C (water drops come from condensing water vapor nearby the glass). A worth note, however, is to consider in the unstable, wavy shape of curve C. This indicated the students' inconsistency (particularly those with high ability) in comprehending the concept of condensation. This confirmed that students had their own preconception regarding concept of condensation.

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Figure 7

(a) item Q5/Dew; (b) option probability curve

(a)

In a glass filled with ice, you can see water drops at the glass. According to you, where do the water drops come from?

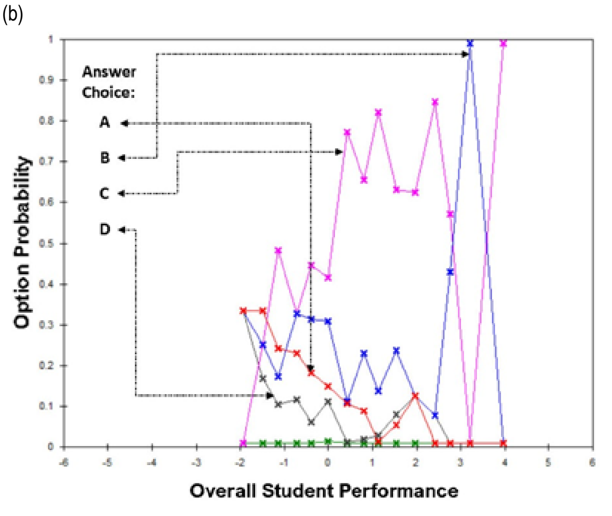
A. Water drops come from melting ice that penetrates the glass wall

B. water drops are the result of reaction between ice and air nearby the glass

C. Water drops come from condensing water vapor nearby the glass

D. Other answer...

(b)



The fourth sample or item Q6/Bubble, as shown in Figure 8(a), measures the students' ability in elaborating characteristics of a particle in the evaporation phenomenon. The option probability curve is displayed in Figure 8(b). The distractor A (air bubbles are Hydrogen and Oxygen particles) was dominantly chosen by students whose ability in a range between -3.0 to 2.0 logit. Moreover, the distractor B (air bubbles are Hydrogen and Oxygen particles) was mostly selected by students whose ability in a range between -3.0 to 0.5 logit. The form of curve A and B were picked by students with low ability was predictable. The curve of right answer C (air bubbles are water molecules), however, shows interesting hint; in the interval range of -2.5 to 3.0 logit, the tip of the curve shows an up-and-down pattern. Moreover, in the level of 1.5 logit, the curve shape of distractors A and B shows a decline pattern, while that of curve C tends to increase. Another finding worth noting was that the curve D (other answers) was picked by some students with high ability (> 2.0 logit). This indicated that particular students had their own preconceptions regarding the evaporation concept.

Figure 8

(a) item Q6/Bubble; (b) option probability curve

(a)

In a container filled with boiling water, you can see air bubbles on the top of it. According to you, what are the composing elements of the air bubbles?

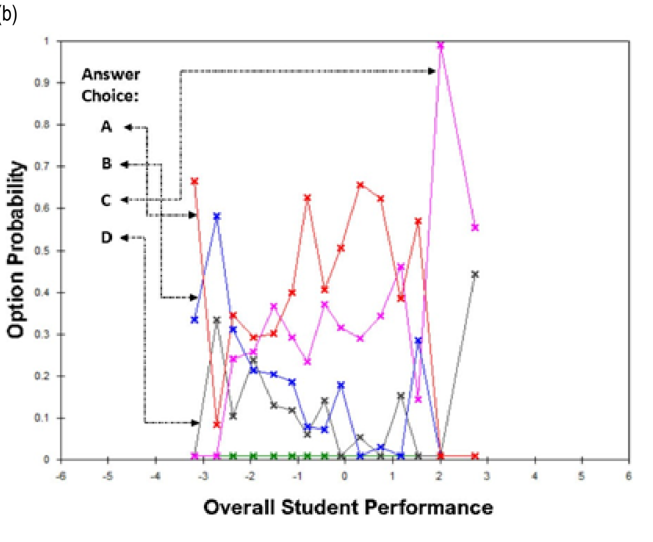
A. Hydrogen and Oxygen particles

B. Air that is dissolved in water

C. Water molecules

D. Other answer...

(b)



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Discussion

The research results indicated that the instruments had good effectiveness, met the requisites of person and item reliability, and showed good construct validity. When applied in evaluating students' conceptual understanding, it was found that: Firstly, almost all students with high ability faced difficulty in understanding the concept of particle size and mass in level 1. The same students found it relatively easy in determining SMRs diagram of particle structure in level 2 or determining the concept of particle regarding evaporation and condensation phenomena in level 3. Secondly, the information of the response pattern of students with high ability was quite consistent, repetitive, and systematic in particular items. This indicates the presence of permanent and latent preconceptions. The analysis of the option probability curve of item Q2/PM/SL (0.88), Q8/PM/LG (0.65), Q5/Dew (-0.63) and Q6/Bubble (0.60) indicates that the approach of item response pattern is able to explore in detail and comprehensively regarding students' conceptual understanding and preconception.

Sequences of verification conducted that involves Rasch model approach shows detailed, accurate, and quantifiable results since the approach integrates development procedure of diagnostic and summative instruments. Several samples of preconception, e.g., item Q2/PM/SL (0.88) and Q8/PM/LG (0.65) indicate that distractor options are potential to be elaborated further in order to investigate tendency of preconception by the students. In addition, it also provides information regarding main idea unknown to the students and their degree of misunderstanding.

The approach employed in this research is an effective illustration to help teacher in evaluating the learning process as well as the students' learning progress. This is due to the integration of qualitative item development procedure and quantitative data analysis, allowing the teachers to explore in-depth on the students' understanding, concepts the students understand and/or do not understand, and misconception. Such findings echo Herrmann-Abell and Deboer (2016) that the integration of Rasch model analysis and probability curve is applicable to diagnose how the students' misconception turns into their overall conceptual understanding. Such an attempt is quite hard to conduct by implementing a conventional approach due to the interdependence of person and item. Rasch model, on the other hand, is able to tackle such interdependence, in which the item and the test difficulty remain invariant and not dependent on which sample that is involved in the initial validation. This signifies that the instrument's items have met the unidimensionality and local independence requirements (Jin et al., 2019; Testa et al., 2019; Wei et al., 2012).

Overall, the research indicated empirical evidence that supported findings by Hoe and Subramaniam (2016); Lu and Bi (2016); Rogat et al., (2011), that students had distinctive preconception as a result of a learning process they experienced. Such preconception was regarded as the inhibitor to the development process of students' conceptual understanding (Soeharto et al., 2019). In this research, students' preconception was found to be repetitive and systematic in each education level. It signifies that the intervention to change students' preconceptions was difficult to conduct by the conventional learning method. A strategic and meaningful learning method is therefore essential to remove students' incorrect preconceptions and develop scientifically correct conceptual understanding. That being said, teachers are demanded to acquire detailed information on the forms and characteristics of students' preconceptions. In conclusion, the item response pattern analysis was an efficient and effective means to acquire such information. The information on students' preconception is important as the basis to develop appropriate and measurable instructional design in solving the students' misconception. This is in line with the previous research studies, arguing that the quality of learning progress is highly dependent on the students' learning process and learning experience (Duschl et al., 2011; Park et al, 2017; Wilson, 2009).

Conclusions

The measuring instrument developed performed well in its validity and reliability, thus, it is deemed applicable in measuring students' conceptual understanding and preconception in elaborating particle characteristics of matter. During the implementation of the instruments, the research finds out that:

1) almost all students with high ability face difficulty in understanding the concept of particle size and mass in level 1. The same students find it relatively easy in determining SMRs diagram of particle structure in level 2, as well as determining the concept of particle regarding evaporation and condensation phenomena in level 3.

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2) There is a significant disparity between students' conceptual understanding based on their educational level.
3) In certain cases, it is found that the distractor item response pattern by high-ability students tends to be consistent, indicating a certain tendency of resistant preconception pattern.

The development of diagnostic instruments with Rasch model approach is deemed as the literacy process for practitioners and researchers in Indonesia. The result indicates that there is no single item that is parallel with both the highest ability and lowest ability students. This calls for further elaboration in order to improve the instrument items' quality. Moreover, an anomaly is found that students with high ability (> 1.0 logit) tend to pick distractor choices. This urges further studies to investigate structured comprehension problems. The research regards that further analysis that integrates conceptual understanding level and items designed in a gradual manner is required to define the characteristics of the students' alternative conception and to measure their learning progress. Echoing this notion, one must integrate the item design and basic principles of chemistry as a reference for further researchers and educational practitioners to implement the same approach conducted in the present research. On top of that, despite not focused on discussing matters regarding students' learning progress individually, the instrument is expected to be beneficial for the teachers to diagnose students' conception in developing an effective and meaningful learning experience.

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