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Development of a two-tier diagnostic test to assess learners' understanding of the particulate nature of gases

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ABSTRACT

The particulate nature of matter is a basic concept in chemistry. It serves as the foundation for higher chemistry concepts that can be applied to gas behaviors and must be understood by the learners during instruction. The study aims to develop a valid and reliable tool to assess the understanding of grade eleven (11) learners on gas concepts as affected by temperature, pressure, and diffusion. Participants were STEM (n=96) and non-STEM (n=139), a total of two hundred and thirty-five (n=235) grade eleven (11) senior high school learners of an accredited private school. Classical Test Theory was used to analyze the initial form of sixteen (16) two-tier items. Difficulty and discrimination indexes were used in the item analysis, while the strength of association was determined using the Phi coefficient. Actions were made based on the combined results of those analyses, such as either selected, revisable, then selected, or deleted, resulting in ten (10) final forms with moderate reliability (r=.637). Learners' understanding of gas concepts was assessed, and alternative conceptions were revealed. The two-tier tools can help teachers analyze learners' understanding of the gas concepts and challenge learners to achieve higher-order thinking skills.

Keywords: *alternative conceptions; particulate nature of gas; two-tier test*

INTRODUCTION

The particulate nature of matter (PNM) is a fundamental concept that serves as a foundation for teaching and learning higher chemistry concepts. It is described and explained more fully by the Kinetic Molecular Theory (KMT), which explains the invisible molecular events underlying the observable phenomena (Lee et al., 1993; She, 2004). It also enables understanding of the structure of matter at the sub-microscopic scale, which is a part of the Chemistry Triplet, namely, macroscopic, symbolic, and sub-microscopic (Johnstone, 1993; Taber, 2013; Talanquer, 2010). The submicroscopic view of matter provides a deeper explanation for the macroscopic behavior of matter (Jansoon et al., 2009). However, it was reported in the study of Ozalp & Kahveci (2015) that most of the time, learners are inclined to attribute the macroscopic properties of matter to microscopic particles.

Over the years, researchers have studied learners' difficulties with gas at the particulate level, which shows a poor understanding of the concepts. But the problem still exists since recently, it was revealed in the study of Ali (2012) and Treagust et al. (2009) that learners have limited ability to demonstrate a good understanding of such a basic concept. In the study of Odom & Barrow (2007), learners had difficulty not only with the particulate nature of matter but also with the diffusion process. Learners had an incomplete understanding and descriptions of how perfume smell spreads and had no clear idea of the difference between the 'smell particles' and air particles (Oyehaug & Holt, 2013). Furthermore, it was revealed that very few learners of different academic years believed that diffusion of particles has 'a need' to move or be moved (Tomazic & Vidic, 2011). Learners had difficulty as well when gas was affected by temperature as revealed in the study of Ozmen et al., (2002), and Ozmen & Kenan, (2007), which showed that most learners think that particle size will increase during heating and decrease in size during cooling. It seems there is also a difficulty with temperature-pressure relationships, as shown in the study of (Ayas et al., 2010), where learners could not relate gas expansion with the particulate nature of temperature.

Considering these difficulties, there is a need to assess the learners' level of understanding of this concept. Assessment is important in education as it helps teachers determine the learners' level of understanding, grade them, and provide them with feedback on their learning process (Tosuncouglu, 2018). It involves measurement processes to come up with quantified results (Magno, 2010) using the appropriate tool.

Several assessment tools have been used in education, but the two-tier multiple-choice diagnostic tests have been recognized as an effective diagnostic tool for assessing meaningful learning among students (Chandrasegaran et al., 2007). The first tier requires learners to provide a response to the first tier, while the second tier requires learners to provide validation for their choice of response to the first tier (Treagust et al., 2013; Treagust et al., 2011) thereby providing a reliable and valid instrument in assessing learners' alternative conceptions and conceptual understanding (Mutlu & Sesen, 2015). It also contributes to an increased awareness of the learners' conceptual status since learners must be skillful in explaining the nature of matter to possess an in-depth understanding of the concepts (Sesli & Kara, 2012; Treagust et al., 2013). Using the two-tier tool, learners who lack complete understanding can be identified and the test can be used to diagnose alternative conceptions (Kumpha et al., 2014). The two-tier test is both diagnostic and instructional (Tsai & Chou, 2002).

Two-tier tests have been developed and used in several chemistry concepts, such as in cell division (Sesli & Kara, 2012), oxidation-reduction (Chiang et al., 2014), chemical bonding (Kumpha et al., 2014), and phase change involving gases (Niroj & Srisawasdi, 2014). Another two-tier test, the Kinetic Particle Theory Instrument (KPTI), was developed to assess learners' understanding of the basic particle nature of matter (Treagust et al., 2009). However, no two-tier test yet has been reported for gas behavior, particularly as it is affected by temperature, pressure, and diffusion as observed in daily activities. Thus, as a first step of this study, an assessment tool was developed utilizing the two-tier multiple-choice format to unveil the students' level and kind of understanding of gas concepts related to (a) the particulate nature of gas, (b) gas behavior due to temperature effects, (c) gas behavior due to pressure effects and (d) diffusion of a gas.

The study aims to develop a valid and reliable two-tier tool, the Particulate Nature of Gas Concept Test (PNGCT), to assess the learners' understanding of the particulate nature of gas and their behavior.

METHODS

Participants. The participants consisted of one hundred thirty-nine (139) non-STEM learners and ninety-six (96) STEM learners, with a total of two hundred and thirty-five (235) learners in a private school in Metro Manila, Philippines. These learners finished junior high school in private (n=146) and public (n=89) schools from the neighboring towns and provinces. They were fluent in English and Filipino languages but used Filipino as their first language at home and belonged to a middle-income class family.

Test Development Procedure. The procedures for developing the ten (10) two-tiered test items in this study were adapted from Treagust, (1988). The procedures were summarized into three stages, namely: (1) defining the content area; (2) creation and revision of two-tiered test items; and (3) expert validation, pilot testing, analysis, and final version as presented in Figure 1.

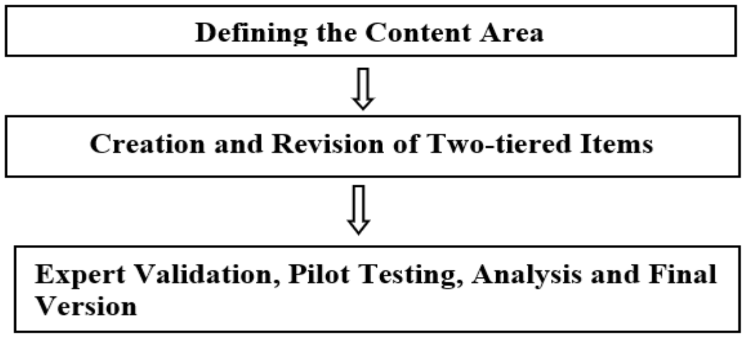


Figure 1. Stages of test development

Phase 1. Learning objectives and content of the Philippine K-to-12 Science Curriculum (Republic of the Philippines Department of Education, 2016) were examined as references in defining the content area. The topic of gases was used to highlight the effect of temperature, pressure, and diffusion, as explained in the Kinetic Molecular Theory.

Phase 2. The creation of a diagnostic tool was based on real-life experiences involving the behavior of gases, and alternative conceptions from previous studies (Merritt et al., 2007) were also considered. For this study, the two-tier questions developed consist of the first tier, which is a multiple choice on the macro molecular observation of gas behavior, while the second tier is possible reasons to justify the answer for the first tier in terms of sub-microscopic phenomena. The items and topics are distributed in the proposed Particulate Gas Concept Test (PNGCT).

Phase 3. Expert validation, Pilot Testing, Analysis, and Final Version. Expert validation of the test was undertaken by experts in chemistry education. The validators were composed of four (4) Chemistry professors at the tertiary level with doctoral degrees and three (3) Chemistry educators at the secondary level with master's degrees who had passed the Licensure Examination for Teachers and with several years of teaching experience. The proposed sixteen (16) item test was revised and improved based on the validators' recommendations.

The improved sixteen (16) two-tier items were pilot tested to senior high school participants consisting of two-hundred and thirty-five (235) learners enrolled in grade 11 in a private school in Metro Manila, Philippines enrolled in School Year 2018-2019.

The test was administered simultaneously during homeroom period to all grade eleven (11) learners which took them around thirty (30) minutes to answer the questions. Answer sheets of learners who failed to submit the assent and consent forms were not checked, whereas the rest of the answer sheets were checked using Zip Grade. Results were exported to an Excel file to come up with a tiered data set where a point was given if both tiers were correct; otherwise, no point was given if only one of the tiers was correct.

Reliability. Internal consistency reliability was used to test whether the responses in the items of a test were consistent with each other internally (Magno, 2010). Several techniques can be used but Cronbach's alpha coefficient of internal consistency was used in the present study.

Research Ethics. The research methodology was approved by the Ethical Review Committee of the University of Santo Tomas Graduate School (Protocol Number GS-2018-PN055). Following ethical principles, the objectives and procedures of the test were explained in simple language to all learners and parent participants. They were also informed that their participation was voluntary, that they could withdraw at any point in the study, that their anonymity was assured, that there were no possible adverse effects on their health, and finally, that it had no bearing on the learner's academic performance. Answer sheets of learners who failed to submit the assent and consent forms were not checked.

RESULTS AND DISCUSSION

Test development. Table 1 presents the distribution of items on the proposed test while Table 2 presents the item placement based on the revised Bloom's taxonomy (Heer, 2015).

Table 1. Distribution of Items on the Proposed Particulate Nature of Gas Concept Test (PNGCT)

Topics	Item Numbers	Number of Paired Items	%
Particulate Nature of Gas	1a, 1b, 2a, 2b, 3a, 3b, 4a, 4b	4	25
Temperature Effects on Gases	5a, 5b, 6a, 6b, 7a, 7b, 8a, 8b	4	25
Pressure Effect on Gases	9a, 9b, 10a, 10b, 11a, 11b, 12a, 12b	4	25
Gas Diffusion	13a, 13b, 14a, 14b, 15a, 15b, 16a, 16b	4	25
Total			100

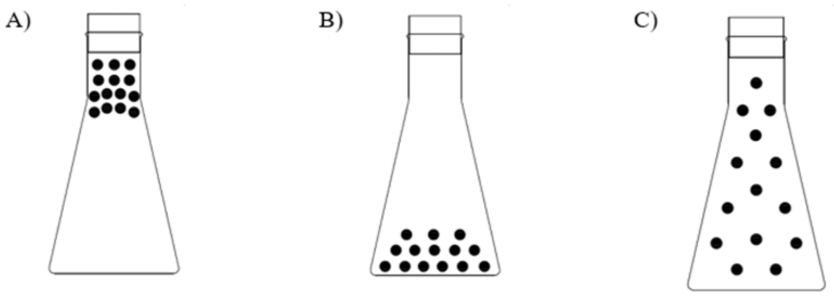
Table 2. Table of Specifications for the 16 items of PNGCT

Level[a]	Learning Outcomes	Items	%
4: Analyze	Learners can compare/relate and analyze gas behaviors	5, 7, 9-13	44
3: Apply	Learners can apply (explain) gas behaviors.	6,14,15,16	25
2: Understand	Learners can understand (describe) gas nature and particles.	1–4, 8	31

[a] Revised Bloom's Taxonomy

Figure 2 shows a sample of the test where tier 1 is the macromolecular event while tier 2 is the explanation at the sub-microscopic level.

Tier 1. Which of the illustrations below BEST represents the arrangement of gas particles inside a covered flask? (Note: Dots represent gas particles).



Tier 2. Which of the following statements BEST explains your answer to the previous question? (Tier 1)

A) Gas particles are heavy and occupy the space below the flask.
B) Gas particles are light and occupy the space above the flask.
C) Gas particles occupy all available space inside the flask.

Figure 2. Sample of test item on the macromolecular event and sub-microscopic level explanation

Item Analysis. Several analyses were conducted on the data sets. Classical Test Theory (CTT) was used to determine the item difficulty, discrimination, and association between two items. Conception analysis was also conducted to assess the level and kind of understanding of the particulate nature of gas.

Classical Test Theory Analysis. Classical Test Theory (CTT) was used in the study where all responses were analyzed using SPSS ver. 20. Item analysis on the difficulty index and discrimination index was conducted. Difficulty Index is the probability that learners can answer a test item correctly and a percentage of learners who correctly answer the questions. A higher value shows that a great number of students were able to answer the test item correctly, indicating an easy item. On the other hand, the discrimination index tells how well an item can distinguish between knowledgeable learners and those who are not (Mehjabeen et al., 2018). To interpret the difficulty index and discrimination index, the following ranges and verbal interpretations were used based on dela Pena Jr et al. (2011, p. 10) and Magno (2010, p. 94), as shown in Tables 3 and 4.

Table 3. Range of Difficulty and Verbal Interpretation

Difficulty Index	Verbal Interpretation
0.76 or higher	Easy Item
0.25 or higher	Average Item
0.24 or lower	Difficult Item

Table 4. Range of Discrimination Index and Verbal Interpretation

Discrimination Index	Verbal Interpretation
0.40 and above	Very Discriminating/Very Good Item
0.30 to 0.39	Discriminating/Good Item
0.20 to 0.29	Moderately Discriminating
0.10 to 0.19	Not Discriminating/Marginal Item
Below 0.10	Poor/Questionable Item

Table 5 shows the item analysis of the PNGCT based on the difficulty index and discrimination index using the SPSS Ver. 20, while association between tier 1 and tier 2 was determined using the chi-square test of association, and results are shown in Table 6. In contrast, the strength of the association was determined by using the Phi coefficient.

Table 5. Item Analysis of the Sixteen (16) Two-tiered Test

Item	Tier 1	Difficulty Index	Verbal Int.	Disc. Index	Verbal Int.	Tier 2	Difficulty Index	Verbal Int.	Disc. Index	Verbal Int.
1	1aPN	0.76	E	0.49	VDisc	1bPN	0.70	A	0.47	VDisc
2	2aPN	0.78	E	0.42	VDisc	2PN	0.74	A	0.40	VDisc
3	3aPN	0.78	E	0.33	Disc	3bPN	0.85	E	0.42	VDisc
4	4aPN	0.79	E	0.46	VDisc	4bPN	0.74	A	0.42	VDisc
5	5aTE	0.48	A	0.15	MarDisc	5bTE	0.46	A	0.18	MarDisc
6	6aTE	0.85	E	0.25	ModDisc	6bTE	0.46	A	0.23	ModDisc
7	7aTE	0.38	A	0.36	Disc	7TbE	0.49	A	0.32	Disc
8	8aTE	0.76	E	0.49	VDisc	8bTE	0.74	E	0.52	VDisc
9	9aPE	0.22	D	0.33	Disc	9bPE	0.33	A	0.26	ModDisc
10	10aPE	0.52	A	0.32	Disc	10bPE	0.45	A	0.24	ModDisc
11	11aPE	0.57	A	0.22	ModDisc	11bPE	0.48	A	0.25	ModDisc
12	12aPE	0.14	D	0.03	P/Q	12bPE	0.79	E	0.29	ModDisc
13	13aD	0.25	A	-0.22	P/Q	13bD	0.56	A	0.30	Disc
14	14aD	0.78	E	0.44	VDisc	14bD	0.71	A	0.53	VDisc
15	15aD	0.72	A	0.35	Disc	15bD	0.70	A	0.39	Disc
16	16aD	0.55	A	0.31	Disc	16bD	0.56	A	0.21	ModDisc

Legends: Int-interpretation; E=easy; A=average; D=difficult; Disc=discriminating/ discrimination; ModDisc=moderately discriminating; VDisc=very discriminating; P/Q=poor/questionable

Table 6. Association Between Tier 1 and Tier 2 Sub-items (a & b, respectively)

Items	Chi-squre	df	p-value	Sig	aPhi	p-value	Sig	Interpretation
1aPN & 1bPN	160.746	1	<0.001	S	0.734	<0.001	S	Strong Positive
2aPN & 2bPN	190.884	1	<0.001	S	0.800	<0.001	S	Strong Positive
3aPN & 3bPN	99.336	1	<0.001	S	0.577	<0.001	S	Weak Positive
4aPN & 4bPN	141.644	1	<0.001	S	0.689	<0.001	S	Strong Positive
5aTE & 5bTE	35.933	1	<0.001	S	0.347	<0.001	S	Weak Positive
6aTE & 6bTE	7.485	1	<0.001	S	0.158	0.006	S	Little or None
7aTE & 7bTE	23.19	1	<0.001	S	0.279	<0.001	S	Little or None
8aTE & 8bTE	175.237	1	<0.001	S	0.767	<0.001	S	Strong Positive
9aPE & 9bPE	75.676	1	<0.001	S	0.504	<0.001	S	Weak Positive
10aPE & 10bPE	20.064	1	<0.001	S	0.259	<0.001	S	Weak Positive
11aPE & 11bPE	37.002	1	<0.001	S	0.352	<0.001	S	Weak Positive
12aPE & 12bPE	2.285	1	0.131	NS	-0.088	0.131	NS	Little or None
13aD & 13bD	50.043	1	<0.001	S	-0.410	<0.001	S	Weak Negative
14aD & 14bD	93.543	1	<0.001	S	0.560	<0.001	S	Weak Positive
15aD & 15bD	25.476	1	<0.001	S	0.292	<0.001	S	Little or None
16aD & 16bD	79.843	1	<0.001	S	0.518	<0.001	S	Weak Positive

Legends: aPhi Coefficient between 0.7 to 1.00 = Strong Positive; between -0.7 to between -1.0 to -0.7 = Strong Negative; between 0.3 to 0.7 = Weak Positive; between -0.3 to 0.3 = Little or None

As shown in Table 6, all tiers (a and b) are significantly associated except for item numbers 12aPE and 12bPE. The strength of association is positively strong for items 1aPN and 1bPN, 2aPN and 2bPN, 4aPN, and 4bPN, as well as 8aTE and 8bTE. The association is weakly positive for items 3aPN and 3bPN; 5aTE and 5bTE; 9aPE and 9bPE; 10aPE and 10bPE; 11aPE and 11bPE; 14aD and 14bD; finally for items 16aD and 16bD. There was little or no positive association for items 6aTE and 6bTE, 7aTE and 7bTE, and finally for items 15aD and a5bD. A weak negative association was found between items 13aD and 13bD.

Table 7 presents a summary table of criteria for selecting items for the initial form of PNGCT. Items 1aPN, 1bPN, 2aPN, 2bPN, 3aPN, 3bPN, 4aPN, and 4bPN were revised and selected since they are revisable and have acceptable discrimination and association values. Items 5aTE and 5bTE were deleted, although they have acceptable difficulty since both tiers have average difficulty and are marginally discriminating. Item 6aTE and 6bTE were deleted. Although they can be revised and have acceptable discrimination, it has little or no association. Items 7aTE and 7bTE were selected since it has acceptable difficulty and discrimination, but it has no association at all, so Item 7bTE was revised to be included in the test items. Both Items 8aTE and 8bTE were revised and selected since they can be revised, have acceptable discrimination, and have an acceptable association. Items 9aPE and 9bPE were deleted, although they can be revised. However, item 9a is difficult and discriminating. Items 10aPE, 10bPE, 11aPE, and 11bPE were selected since they have acceptable difficulty, discrimination, and association. Items 12aPE and 12bPE, 13aD, and 13bD were deleted since they do not have acceptable difficulty, discrimination, or association.

Table 7. Summary of Analyses on the Sixteen (16) Initial Form of the PNGCT and Selection of Items for Ten (10) Two-tiered Items

Items	Area	Difficulty	Discrimination	Associations	Actions
1aPN & 1bPN	Particulate Nature	R	A	A	RS
2aPN & 2bPN	Particulate Nature	R	A	A	S
3aPN & 3bPN	Particulate Nature	R	A	A	RS
4aPN & 4bPN	Particulate Nature	A	A	A	S
5aTE & 5bTE	Temperature Effect	A	R	A	**D**
6aTE & 6bTE	Temperature Effect	R	A	U	**D**
7aTE & 7bTE	Temperature Effect	A	A	U	RS
8aTE & 8bTE	Temperature Effect	R	A	A	RS
9aPE & 9bPE	Pressure Effect	R	A	A	**D**
10aPE & 10bPE	Pressure Effect	A	A	A	S
11aPE & 11bPE	Pressure Effect	A	A	A	S
12aPE &12bPE	Pressure Effect	U	U	U	**D**
13aD & 13bD	Diffusion	U	U	U	**D**
14aD& 14bD	Diffusion	R	A	A	S
15aD & 15bD	Diffusion	A	A	A	S
16aD &16bD	Diffusion	A	A	U	**D**

Legends: A=accepted; R=revisable; U=Unacceptable; RS=revisable and selected; S=selected; D=deleted

Reliability of the ten (10) two-tier test (235 persons). Using the Classical Test Theory, internal consistency reliability was assessed using Cronbach's alpha, which measures how closely the items are as a group. A value of .637 was obtained, corresponding to acceptable or moderate reliability (Bond & Fox, 2015; Salvucci et al., 1997, p. 115). A moderate Cronbach alpha has been associated with fragmentary knowledge (Verschaffel et al., 2010) and alternative knowledge (Lu & Bi, 2016; Luxford & Brentz, 2014). Furthermore, according to Gronlund (1993), a test with moderate reliability is acceptable for classroom tests and considered acceptable reliability.

Table 8 presents the summary of the distribution of valid items. There are four (4) items about the particulate nature of matter, and two (2) items each for temperature effect, pressure effect, and diffusion.

Table 8. Distribution of Items of the Final and Valid Ten (10) Two-tiered Form of the PNGCT (SY 2018-2019)

Topics	Item Numbers	Number of Items
Particulate Nature of Gas	1,2,3,4	4
Temperature Effects on Gases	7,8	2
Pressure Effect on Gases	10,11	2
Gas Diffusion	14,15	2
Total		10

Table 9. Placement of the Final 10 and Valid Ten (10) Two-tiered Forms of the PNGCT (SY 2018-2019)

Levels a	Learning Outcomes	Items	%
4: Analyze	Learners can compare/relate and analyze gas behaviors	7, 10, 11	30
3: Apply	Learners can apply (explain) gas behaviors.	14,15	20
2: Understand	Learners can understand (describe) gas nature and particles.	1–4, 8	50

[a] Revised Bloom's Taxonomy

Conception Analysis. Conception analysis was conducted to probe the alternative knowledge, which was hinted to be associated with the moderate value of the Cronbach alpha. When a learner could answer both tiers correctly, it was inferred that the learner had a correct knowledge of the concept, consistent with the scientific principles. However, suppose the learner fails to answer one or both tiers, the learner does not have a complete understanding of the concept, which might lead to concepts often inconsistent with scientific conceptions, leading to faulty thinking. In this paper, the term 'alternative conceptions' will be used to mean a conception that differs significantly from that which is socially agreed upon by the scientific community (Griffiths & Preston, 1992; Henriques, 2002; Treagust, 1988). Our analysis of learners' responses to the PNGCT diagnostic instrument identified an alternative conception by a wrong response of at least 10% of the learners (Treagust, 2014).

Conception analysis was also conducted since items on PNGCT were classified based on the level of understanding specified in the revised Bloom's taxonomy (Heer, 2015). A rubric for learners' kind of understanding was adopted from Helmi et al. (2019) as presented in Table 10. Complete understanding means the learner has a correct knowledge of the concept consistent with the scientific principles. However, when the learner is correct at a certain point but lacks complete knowledge of the concept, maybe due to confusion, it is considered an alternative conception, classified as partial understanding, wrong understanding, or no understanding. Partial understanding means that learners have correct conceptual understanding at the macroscopic level but incorrect understanding at the microscopic level. On the other hand, wrong understanding means that the learner is simply guessing while no understanding means the learner lacks knowledge of the concept.

Table 10. Criteria for the Classification on the Kind of Understanding.

Kind of Understanding	Tier 1	Tier 2
Correct Understanding	Correct	Correct
Partial Understanding	Correct	Incorrect
Wrong Understanding	Incorrect	Correct
No understanding	Incorrect	Incorrect

Table 11 summarizes the percentage of grade eleven learners selecting each response combination in the items of the PNGCT. The percentage of the correct combination is highlighted in bold fonts, and an asterisk indicates the identified alternative conception in an item.

Table 11. The Percentage of Grade 11 Learners (n=235) Selecting each Response Combination for each Valid and Reliable Ten (10) Two-tiered Items of the PNGCT.

Item	Tier 1	Tier 2 (Options)				Total
	(Options)	A	B	C	D	
1PN	A	1.30	1.70	5.10	---	8.10
	B	0.40	11.1*	1.30	---	12.80
	C	**71.50**	6.00	1.70	---	79.10
	% of Total	73.20	18.70	8.10	---	100.00
2PN	A	0.40	12.80*	1.70	---	14.90
	B	0.90	0.40	0.40	---	1.70
	C	2.10	3.00	**78.30**	---	83.40
	% of Total	3.40	16.20	80.40	---	100.00
3PN	A	1.70	0.90	2.10	---	4.70
	B	0.40	6.40	4.70	---	11.50
	C	0.00	2.60	**81.30**	---	83.80
	% of Total	2.10	9.80	88.10	---	100.00
4PN	A	**76.60**	5.50	1.30	---	83.40
	B	2.60	5.10	0.00	---	7.70
	C	0.40	0.40	1.70	---	2.60
	D	0.00	0.00	6.40	---	6.40
	% of Total	79.60	11.10	9.40	---	100.00
7TE	A	1.30	18.70*	7.20	1.70	28.90
	B	9.40	2.60	**17.40**	1.70	31.10
	C	5.10	9.80	19.10*	6.00	40.00
	% of Total	15.70	31.10	43.80	9.40	100.00
8TE	A	0.90	2.10	3.40	---	6.40
	B	10.60*	1.30	1.30	---	13.20
	C	2.60	**74.90**	3.00	---	80.40
	% of Total	14.00	78.30	7.70	---	100.00
10PE	A	20.40*	**21.70**	3.40	---	45.50
	B	16.20*	14.00*	2.10	---	32.30
	C	8.50	3.40	10.20*	---	22.10
	% of Total	40.90	45.30	13.80	---	100.00
11PE	A	1.30	0.90	4.70	0.90	7.70
	B	**29.80**	14.50*	4.30	6.40	54.90
	C	12.80*	17.40*	2.60	2.10	34.90
	D	0.40	1.30	0.90	0.00	2.60
	% of Total	44.30	34.00	12.30	9.40	100.00
14D	A	**69.80**	7.20	2.60	---	79.60
	B	3.40	8.50	2.60	---	14.50
	C	1.30	3.00	1.70	---	6.00
	% of Total	74.50	18.70	6.80	---	100.00
15D	A	3.40	8.90	0.40	2.60	15.30
	B	4.70	**60.00**	2.10	7.70	74.50
	C	1.70	4.30	2.60	1.70	10.20
	% of Total	9.80	73.20	5.10	11.90	100.00

Notes: Figures in bold indicate the correct answer.
Figures with an asterisk (*) indicate a major alternative conception (>10%)

Table 12. Summary of Alternative Conceptions as Determined from the Administration of the PNGCT on Learners (n=235).

Item	Alternative Conceptions	%
	Particulate Nature of Matter	
1PN	Gas particles are separated from each other by a moderate distance.	11.1
2PN	Gas particles are light and occupy the space above the container.	12.8
	Temperature Effects (Cooling)	
7TE	The bottle will not change while individual air molecules inside the bottle will get closer to each other upon cooling.	19.1
7TE	The bottle will bulge out while individual air molecules inside the bottle increase their movements upon cooling.	18.7
	Temperature Effects (Heating)	
8TE	Air molecules moved slower and closer to each other upon heating.	10.6
	Pressure Effects	
10PE	Gas pressure in smaller containers is greater but directly proportional to volume.	20.4
10PE	Gas pressure in smaller containers is lesser and directly proportional to volume.	16.2
10PE	Gas pressure in a small container is less, but pressure is inversely proportional to volume.	14.0
10PE	Gas pressure on both containers is equal since pressure is not related to volume	10.2
11PE	Can visually represent the bubble size correctly as it goes up the surface but could not give the relative explanation to the visual representation.	14.5
11PE	Visual representations showed that gas volume decreases and chose a parallel reason that the volume of the gas decreases as the pressure of the surrounding water decreases.	17.4
11PE	Visual representations showed that gas volume decreases but chose a non-parallel reason that the volume of the gas decreases as the pressure of the surrounding water decreases.	12.8

Particulate Nature of Matter. Item 1PN deals with the general arrangement of gas particles. Table 11 shows that it may seem easy due to the high percentage (71.5%) who got the correct answer. The item was classified under the understanding level (Table 9). Still, some non-understanding learners (11.10%) (Table 12) have alternative conceptions that gas particles are separated from each other by a moderate distance. These results are like the study of Aydeniz et al. (2012), where the pre-tests of control and experimental groups believed that gas particles are irregularly distributed in any enclosed space. However, this result differs from the study of Wah et al. (1993), where learners believed that gas particles are closely packed.

Item 2PN is about the arrangement of gas particles in a closed container. Table 11 shows that it may seem easy due to the high percentage (78.3%) who got the correct answer (understanding level, Table 9). Still, as shown in Table 12, there is a perceived alternative conception (12.8%) that the gas particles are light and occupy the space above the container, extending wrongly to the particles the property of the macroscopic gas system. This result is like the study of Tatar (2011) and Wah et al. (1993), where learners believed that particles have low density, are not affected by gravity and are too light to fall to the bottom.

Items 3PN and 4PN have no alternative conception, and it seems easy due (understanding level, Table 9) to the high percentages who got the correct answer (Table 11). It showed that learners have a clear concept of particle movements. It seems that learners could relate the macromolecular events of the balloon to its sub-micromolecular characteristics of gases.

Temperature Effect on Cooling. Item 7TE was about the gas behavior on cooling. Table 11 shows that it appears to be the most difficult due to the very low percentage (17.4%) who got the correct answer. Being difficult, this item revealed two alternative conceptions. First, some of the learners were classified with wrong understanding (19.10%) (Table 12). These learners correctly knew the submicroscopic effect of cooling (i.e., that air molecules will get closer), but failed to relate this effect correctly to the macromolecular level. Second, another group of learners classified as non-understanding learners (18.70%) (Table 12) predicted incorrectly that the bottle would bulge and gave an answer in the second tier that correctly supported this wrong prediction. These learners have alternative conceptions of the effect of lowering the temperature in the movement of the gas molecules. These results indicate that a mismatch occurs between macromolecular observations and micro-molecular events. Moreover, item 7PE is under analysis level (Table 9), indicating that learners find it difficult to analyze the situation.

Temperature Effect on Heating. Item 8TE is about the gas behavior on heating. Table 11 shows that this item may be considered an easy item due to the high percentage (74.9%) who got the correct answer and had an understanding level (Table 9). However, an alternative conception for some learners classified as non-understanding learners (10.60%) (Table 12) revealed that they were not able to predict the particle movement when the gas is heated, and they believed that air molecules move slower and closer to each other upon heating. This alternative conception was also observed in the study of Lin & Cheng (2000), where representations of molecular movements showed that molecules stay away from heat. It seems that the sub-micromolecular events were not parallel to the scientific view that air molecules should move faster and be far apart when heated.

Pressure Effect. Item 10PE is about a gas' volume and pressure relationships in a closed container. Table 11 shows that this item seems difficult due to the very low percentage (21.70%) who got the correct answer and were under analysis level (Table 9). It also showed that some learners (20.40%) (Table 12) with partial understanding were able to relate the volume and pressure with the help of visual representations, that pressure inside the smaller flask is greater than the pressure inside the bigger container but reasoned that the pressure of the gas is directly proportional to its volume. These learners are aware that the gas pressure was greater in a smaller container since the drawing was shown but were unaware of the volume and pressure proportionality. For this group of participants, it is considered an alternative conception that gas pressure in smaller containers is greater and/but directly proportional to volume. However, there are groups of learners classified as non-understanding learners (16.20%) and (10.20%) (Table 12) who were not fully aware of the gas pressure inside the containers and were not aware of the volume and pressure proportionality and considered as alternative conceptions. Furthermore, some of these learners are classified as learners with the wrong understanding (14%) (Table 12) and have alternative conceptions that gas pressure in a small container is less but are not aware of the volume and pressure proportionality. This implies that learners could not form the correct concept, possibly due to instruction or textbook representation.

Item 11PE is about the volume and pressure relationships concerning particle distance with visual representations of bubble sizes as they go up to the surface (analysis level, Table 2). A low percentage (29.80%) of learners got this item correct, which seems difficult for them (Table 11). Being difficult, several alternative conceptions were noted. It showed that some learners with partial understanding can acknowledge visual representations of the bubbles as pressure is decreased. Still, they were not able to predict the gas behavior inside the bubble at the sub-micro level. These learners could visually represent the bubble size as it goes up the surface but were not able to give a relative explanation to the visual representation and considered it as an alternative conception (14.50%) (Table 12). A portion of these learners are classified with wrong understanding (12.80%) (Table 12) had a visual concept that the volume of the gas decreases but reasoned that the volume of the gas increases as the pressure of the surrounding water decreases and is considered as an alternative conception for this group of participants. Furthermore, another group of learners is classified as non-understanding (17.40%) (Table 12) with a visual representation that bubbles become smaller as they go up the surface and a wrong parallel reason that the volume of the gas decreases as the pressure of the surrounding water decreases.

Diffusion. Item 14D focuses on the diffusion of two gases with different molar masses (apply level, Table 9). Item analysis in Table 11 revealed that most of the participants got the correct answers (69.8%), and it seems like an easy item without any alternative conception. It shows that participants in this study could relate the macromolecular events of diffusion to the sub-micromolecular characteristics of gases, even if they have different molar masses.

Furthermore, Item 15D concerns gas particles moving in all directions (apply level, Table 9). This item was considered an easy item since most of the participants (60.0%) were able to answer the correct combinations (Table 11), and no alternative conception was revealed since most of the participants were able to get the correct answers (60.0%). It shows that participants in this study could relate the macromolecular events of diffusion to the sub-micromolecular molecular characteristics of gases. Learners have a correct understanding of items at the application level.

It can be noted that almost all items have alternative conceptions except items 3PN, 4PN, 14D, and 15D. These results point out that this group of participants had a complete understanding of particle motion (3PN), the gas behavior inside the balloon (4PN), the diffusion of two gases with different molar masses (14D), and gas diffusion inside a closed environment (15D).

CONCLUSIONS

A ten-item two-tier multiple-choice test on the Particulate Nature of Gas Concept test (PNGCT) was developed, which is valid and reliable based on the Classical Test Theory. The items focused on applying the properties of gas particles to explain temperature effects, pressure effects, and diffusion of gases.

Analysis of the responses in the test revealed alternative conceptions of the learners on the particulate nature of gases with the effect of temperature and pressure on gas behavior. It was noted that the alternative conceptions occurred in items identified as difficult and on the analysis level. No alternative conception was observed on some easy items (understanding and application levels). Different kinds of understanding were noted.

The developed tool will provide significant information on learners' alternative conceptions about the topic and can help teachers plan classroom instruction. to provide meaningful understanding and achieve higher-order thinking skills. Furthermore, it could also contribute to the enhancement of chemistry teachers' instructional skills in assessing learners' ability to use multiple levels of representation.

The paper presented the first iteration, but it fills a gap in literature as there is no existing two-tier instrument on the particulate nature of gases and their behavior when affected by temperature, pressure, and gas diffusion. The two-tier PNGCT can be further improved by being utilized for more research.

The result of this study highlights the need to develop students' conceptions of the nature of particles as the foundation of learning advanced chemistry. The students tend to focus on their understanding of gas behaviors at the macroscopic level (such as the shape of the container) instead of at the microscopic level of interpreting the dynamic nature of particles (such as the sizes of particles and their motion). The instrument developed in this study can be a formative assessment for understanding students' progressive path in the chemistry classroom.

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CONFLICTS OF INTEREST

The authors have no conflicts of interest to declare.

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