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Learners' mental representations of the particulate nature of gases

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ABSTRACT

This paper aims to describe selected Filipino learners' mental representations of gas particles affected by temperature, pressure, and diffusion and identify possible alternative conceptions. The study employed a qualitative method that participants were in grade 11 of a local private institution. Results indicated seven mental representations on gas behaviours namely, motion of hot and cold gas (type 1), motion and size of hot and cold gas (type 2), motion and size of hot gas (type 3), motion and size of cold gas (type 4), motion of hot gas (type 5), motion of hot gas and size of cold gas (type 6), and demented (type 7) and were discussed accordingly. Type 1 is the major mental representation for these learners and alternative conceptions were described. The learners have similar alternative conceptions to other studies on bigger hot particles, and some alternative conceptions particular to them: denting hot bottles, same bottle shape in cold gas, uncertain on particle size, increasing or decreasing particle sizes on diffusion. Implications for teaching were discussed.

Keywords: alternative conception, gas behaviours, mental representation

INTRODUCTION

The particulate nature of matter is a fundamental concept in chemistry, serving as the foundation for higher chemistry concepts (Adadan, 2014) and taught early in education. Chemistry views matter as particles–atoms, molecules, or ions–and relates their properties and changes to the microscopic structure. Johnstone's (1993) "chemistry triplet" integrates this view into three domains:

(1) macrochemistry (observable),

(2) sub-microchemistry (atomic, molecular), and

(3) representational chemistry (symbols and equations) (Taber, 2013).

The sub-microscopic view explains phenomena at the observable level, using models to connect macroscopic observations and representational chemistry. Teaching should avoid overloading learners with sub-micro-symbolic connections, instead introducing levels progressively (Johnstone, 2000; Taber, 2013; Talanquer, 2011).

Understanding the particulate nature of matter helps explain physical phenomena like phase changes (Wah et al., 1993) and chemical processes like dilution (Jansoon et al., 2009), equilibrium (Çelik et al., 2009), chemical reactions (Chandrasegaran et al., 2009; Lajium, 2013), and chemical bonding (Abd Halim et al., 2013). Moreover, it can explain gas behaviour in compression and expansion (Wah et al., 1993), and diffusion (mix of gas) at different pressures (Liang et al., 2011). However, learners struggle with this abstract concept, making it difficult to grasp higher chemistry. Studies show understanding is often problematic (Ferouni et al., 2012).

Learners benefit from visuals and shifting among chemical representations (Bodner & Domin, 2000). It is assumed that learners can relate symbolic representation with macroscopic representation simultaneously (Chittleborough & Treagust, 2007), yet many remain "stranded" at the macro level (Johnstone, 1991). Learners lacking a basic understanding of the sub-microscopic level find chemistry especially difficult (Devetak & Glazar, 2011). The invisibility of gas particles adds to these challenges, making it harder for students to relate microscopic and symbolic representations (Supasorn, 2015).

The sub-microscopic level being invisible is the major obstacle in learning chemistry concepts, one of which is a gas concept (Azizoglu & Geban, 2004). According to Devetak et al. (2009), as reflected in **Figure 1**, the mental model will provide connection

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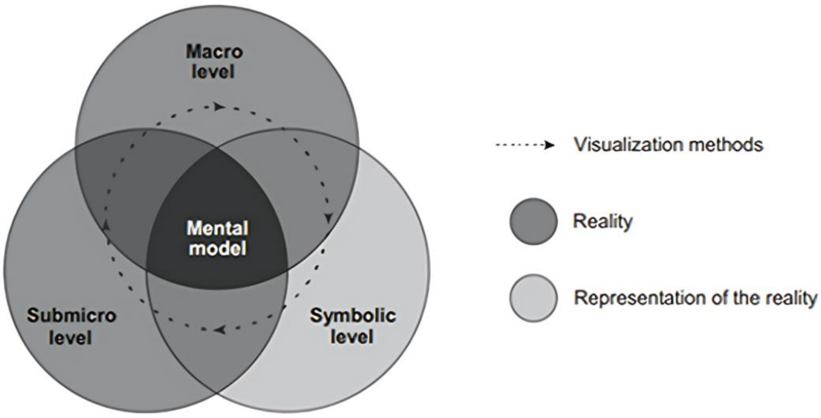


Figure 1. Interdependence of three levels of science concepts (Devetak et al., 2009)

and overlapping among macro chemistry, representational/symbolic chemistry, and sub-micro chemistry, and a factor of storing knowledge in long-term memory (LTM); thus, deep learning will occur (Devetak & Glazar, 2011).

Craik (1943) proposed that the mind can create an internal model of reality through perception, which functions like an external model. This "small-scale model" helps predict events, reason, and explain (Johnson-Laird, 2010). Cognitive psychologists interpret this model as a mental representation–an internal structure that mirrors external objects previously perceived (Feist & Rosenberg, 2012). Mental models have applications in areas like human-computer interaction (Staggers & Norcio, 1993), science education (Rapp, 2005), and cognitive linguistics (Bekhta, 2005). Norman (1983) described mental models as analogs of reality, showing how cognitive ability relates to the world. They also act as knowledge storage structures to solve complex problems, including those in everyday science experiences (McClary & Talanquer, 2011). This study uses "mental representations" broadly to describe students' responses to gas particle scenarios. A mental representation is a mental object with meaning, similar to how pictures represent objects (Pitt, 2022). Some researchers use "mental models" interchangeably with "mental representations." Recently, Talanquer (2025), used "mental representations".

Mental models can be used to appreciate chemical phenomena, but according to Chittleborough et al. (2002), learners' lack of mental model is a constraint to understanding deeper chemical phenomena. Learners can also use mental models to explain the relation between one's cognitive activity and the world (Tarcio Borges & Gilbert, 1999) and to give explanations and predictions (Johnson-Laird, 2002). Mental models, being small-scale and internal representations, are individually constructed by the learner as they interact with reality (Akaygun, 2016). It was mentioned in the study of Ling et al. (2024), that mental models can be achieved using a teaching strategy such as modelling using multiple connected representations. However, these mental models are not meant to substitute alternative conceptions (Lajium, 2013).

Studies were conducted on mental models in Chemistry concepts to undermine learners' cognitive abilities. They were used in acids and base (Amalia et al., 2018; Lin & Chiu, 2007, 2010), stoichiometry (Sunyono et al., 2015), molecular geometry and polarity (Wang & Barrow, 2011), atoms and molecules (Zarkadis et al., 2017), chemical bonding (Abd Halim et al., 2013), basic concepts in chemistry (Yayla & Eyceyurt, 2011), dilution (Jansoon et al., 2009), chemical reactions (Katmiati et al., 2017), organic chemistry (Hegarty et al., 2013), and thermochemistry (Wiji & Mulyani, 2017). Mental model studies were also conducted in Physics topics such as galvanic cells (Supasorn, 2015), gravity (Ozturk & Doganay, 2013), and heat convection (Sari & Saepuzzaman, 2015). Interestingly, it was also conducted in physical education subjects (Bonelo, 2008). However, few studies on mental models related to the gas concept have been conducted: vapor pressure by Tumay (2014), particle nature of matter by Adbo & Taber (2009), phase transition by Chiu and Wu (2013), gas particle behaviour by Chiu and Chung (2013), ideal gas by Chung and Chiu (2012), and mix-gas of an ideal gas by Chung and Chiu (2007). These mental model studies on the gas concept were conducted in different countries: Sweden (Adbo & Taber, 2009), Taipei, Taiwan (Chiu & Chung, 2013; Chiu & Wu, 2013; Chung & Chiu, 2007, 2012; Jong et al., 2015), and Turkey (Tumay, 2014).

Previous studies have explored mental models in chemistry and physics topics, but few focus on gas concepts, particularly in the Philippines. It is unclear whether some learners in the Philippines share the same thinking about gas particles since the curriculum and teaching might be different from other countries. Existing data indicates Filipino learners struggle with science, evident in the third international mathematics and science study (TIMSS) 2019 results, where Philippine scores fell below the international mean (Mullis et al., 2020) and science performance seems to have declined over the years (Martin et al., 2015; Mullis et al., 2020). In addition, the national achievement test result showed that the mean percentage score is slightly lower for 2018-2019 compared to the previous year of 2017-2018 (Behiga, 2022).

Findings of this paper can serve as a valuable tool towards realizing how selected Filipino learners understand gas behaviours and eventually improve instructions. This study focuses on achieving selected Filipino learners' mental representations of gas particles. Philippine K to 12 science curriculum (Republic of the Philippines Department of Education, 2016) was examined as the foundation of the study. Participants were asked to depict their mental representations at three levels of chemical representations: macroscopic (perception), sub-microscopic (cognition), and symbolic (representations), as they relate to each level (Treagust, 2003).

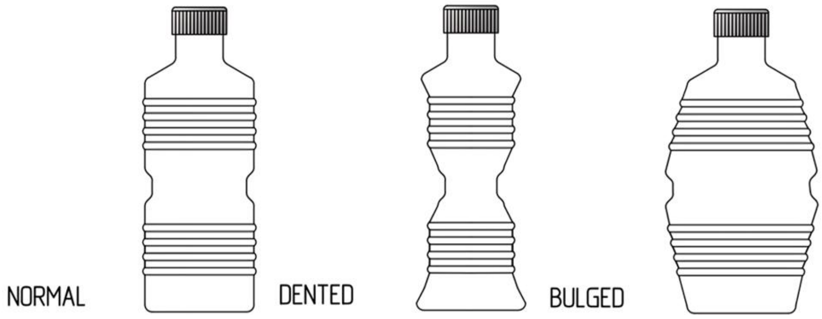


Figure 2. Bottles for temperature effects (Source: Authors' own elaboration)

This study aims to explore the mental representations of selected Filipino learners regarding gas behavior, focusing on temperature, pressure, and diffusion. It seeks to address two key questions:

1. How do Filipino learners conceptualize gas behavior at the particulate level?
2. What alternative conceptions do these learners hold regarding gas behavior?

MATERIALS AND METHODS

This qualitative study relies on participants' responses to understand Filipino learners' mental representations of gas behavior. It uses a systematic approach, analyzing data through open and axial coding with pictorial representations to develop these mental representations.

Participants

The participants were grade 11 students from a private senior high school in Metro Manila, Philippines, enrolled in various K to 12 strands: science, technology, engineering, and mathematics (STEM), general academic strand (GAS), accounting, business, and management (ABM), and humanities and social sciences (HUMSS). Thirty students were selected using stratified sampling based on their responses to the particulate nature of gas concept test (PNGCT), exceeding the typical sample size of 25 to ensure comprehensive data collection (Thomson, 2010). These students had previously studied the particulate nature of matter in grade 8 and gases in grade 10. Aged 16 to 17, they were fluent in English and Filipino/Tagalog, with Filipino/Tagalog being the dominant language at home.

Instrument and Procedures

At the start of the academic year, participants were invited to join the study and signed informed consent forms. Thirty-minute audio-recorded, semi-structured interviews were conducted to explore their understanding of gas behavior. The interviews followed a protocol developed by the authors and pilot-tested on non-participants to ensure a smooth data-gathering process (Hunter, 2012). Questions were designed to contextualize gas behavior, beginning with preliminary ones like, "Can you see anything inside the flask?" Participants were also asked about an empty plastic bottle and a scenario involving hot gas, followed by, "Can you describe the size and motion of gas particles?" They drew and explained their responses. Similar questions addressed pressure effects and diffusion. Pre-drawn images were provided (**Figure 2**), but participants could modify or redraw them to match their ideas. They were assured that their responses would not affect their grades.

Data Analysis

Interview data and participant drawings were analyzed through coding. In open coding, responses were reviewed line by line, assigned major codes, and then organized into axial coding (**Figure 3**). These major codes were combined with strategies to develop mental representations. Sub-codes were added where needed and integrated into pictorial representations (**Figure 4**). Codes from key responses (e.g., "moving faster" was coded as particle motion) were categorized as scientific or non-scientific, highlighting patterns and connections. Pictorial representations showed each participant's mental representations , using a plus (+) or minus (-) to indicate correct or incorrect understanding. By overlapping these visuals, participants with similar responses were grouped, allowing themes to emerge that reflected their grasp of the three levels of chemical representation. Sample interview excerpts and drawings illustrate the findings.

Moreover, for this study, frequencies, and percentages of responses for a particular question were analyzed; > 10% is considered a major alternative conception, a cut-off indicator for alternative conceptions by (Treagust, 2006).

Reliability was assured by avoiding bias so the study could be trusted, and inter-rater reliability was employed where multiple coders applied codes. Initially, three coders gave similar codes, discussed the codes, and then came up with 100% verbal agreement to use one code for a particular segment of the interview. Member checking procedures were also conducted so further validate the data. Significant responses were translated into English using Google translate, corrected further with Grammarly, and checked by two competent professors with master's degrees; one is teaching English while the other is teaching Filipino, so that the non-Filipino members could relate to the Tagalog responses. To maximize trustworthiness, participant and respondent validation were utilized (Thomson et al., 2011).

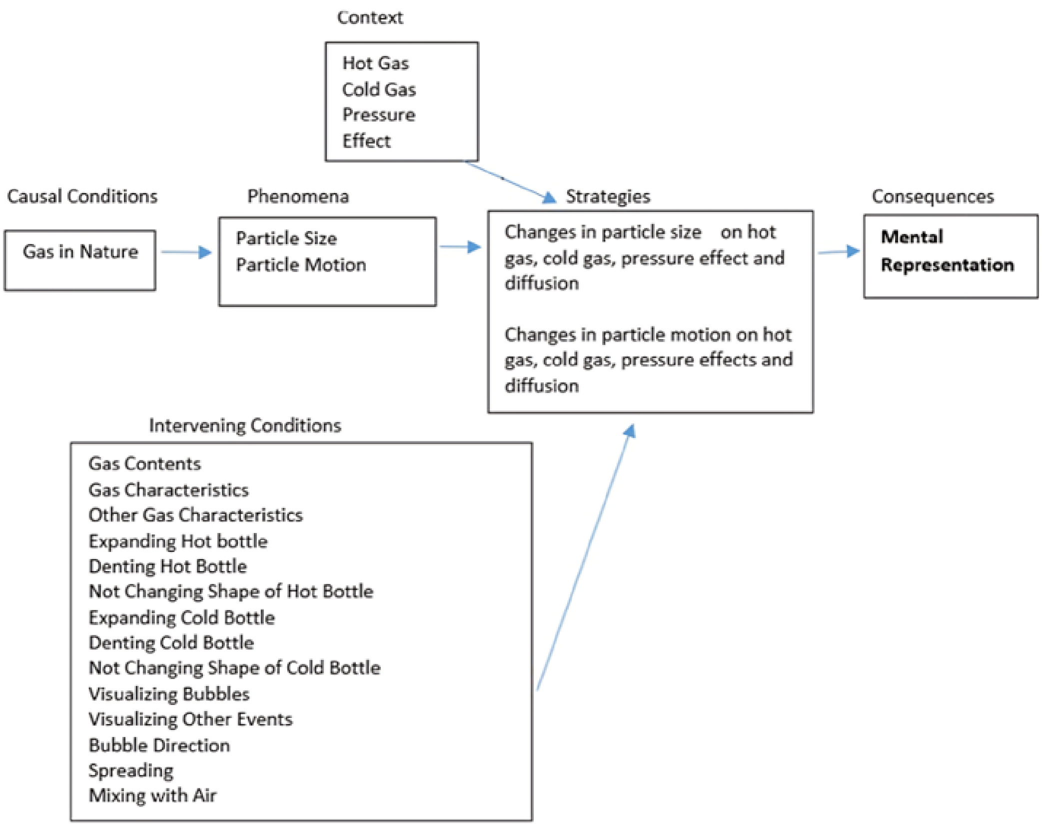


Figure 3. Axial coding (Source: Authors' own elaboration)

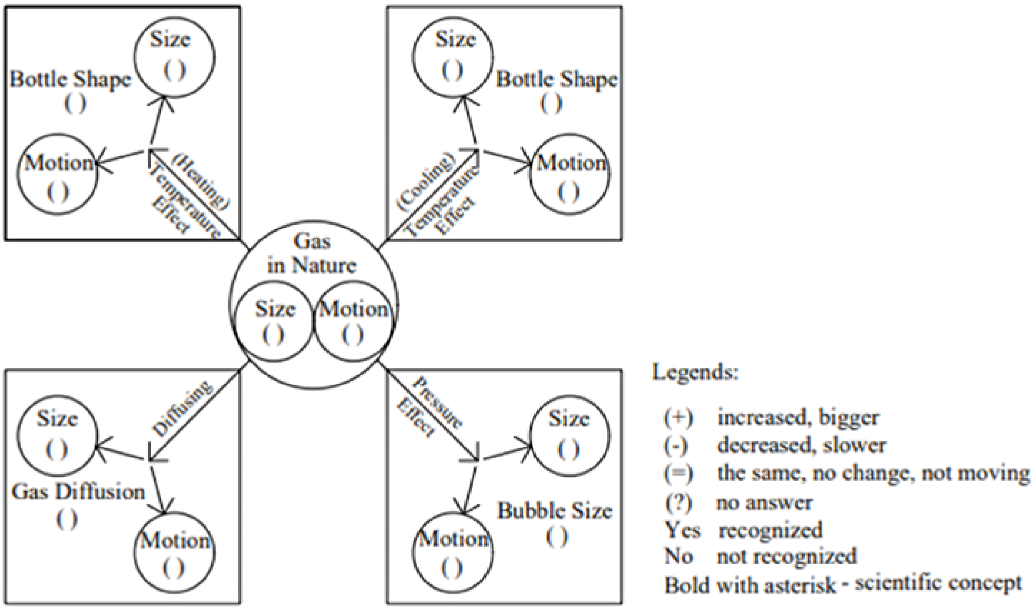


Figure 4. Pictorial representations (Source: Authors' own elaboration)

Ethical Approval

Before data collection, ethics review approval was obtained from the Ethics Review Committee (protocol number GS-2018-PN055), and permission was sought from the president, vice president for academics and research as well as the senior high school principal to conduct the study. The informed consent and assent details, adapted from the Philippines's national ethical guidelines for health and health-related research (Philippine Health Research Ethics Board, 2017), were discussed. Then, their consent and assent were obtained. The participants allowed audio recordings, and only the researchers had access to the interview and drawings, which would be kept until the study was completed. To maintain confidentiality, each participant was assigned a code.

Table 1. Distribution of types of mental representation

Types	Descriptions	n	Total
Type 1	Motion for hot and cold gas		11
Type 1.1	Hot and cold bottle shape	4	
Type 1.2	Mixed with air or spreading	7	
Type 2	Motion and size for hot and cold gas	4	4
Type 3	Motion and size for hot gas	2	2
Type 4	Motion and size for cold gas	4	4
Type 5	Motion of hot gas	5	5
Type 6	Motion of hot gas and size of cold gas	2	2
Type 7	Demented (no pattern)	2	2
	Total		30

Table 2. List of major alternative conceptions and percentages

Types	Descriptions	n	Total	Alternative Conceptions
Type 1	Motion for hot and cold gas		11	
Type 1.1	Hot and cold bottle shape	4		(a) Hot particles will increase in size (n = 3, 10.0%) & (b) cold particles will decrease in size (n = 3, 10.0%)
Type 1.2	Mixed with air or spreading	7		(a) Denting hot bottle (n = 4; 13.3%), (b) same cold bottle shape (n = 5; 16.7%), & (c) no idea on particle size on diffusion (n = 3, 10%)
Type 2	Motion and size for hot and cold gas	4	4	None
Type 3	Motion and size for hot gas	2	2	None
Type 4	Motion and size for cold gas	4	4	Decreased particle size on diffusion (n=3; 10.0%)
Type 5	Motion of hot gas	5	5	(a) Denting hot bottle (n = 3; 10.0%) & (b) increasing particle motion on diffusion (n = 5; 16.6%)
Type 6	Motion of hot gas and size of cold gas	2	2	None
Type 7	Demented (no pattern)	2	2	None
	Total		30	

RESULTS AND DISCUSSIONS

Mental representation in this study is the whole picture of how learners view the different gas behaviours based on scientific knowledge. It presents the types of mental representation of selected Filipino learners in different study contexts. Utilizing **Figure 4**, the analysis showed that different mental representations were evident to the participants. Trends in temperature and pressure effects, as well as diffusion, were examined. Different mental representations were developed on hot and cold gas, but no pattern was developed regarding pressure effect and diffusion. However, subtypes were developed in type 1. Alternative conceptions were also manifested, but according to Lajium (2013), mental representations are not meant as substitutes for alternative conceptions.

Table 1 presents the summary of types of mental representations exhibited by the learners, while **Table 2** presents a list and percentage of major alternative conceptions.

Type 1. Mental Representation

Type 1 mental representation is for the motion of hot and cold gas, where participants have a good concept of fast hot gas particles and slow cold gas particles (n = 11, **Table 1**). Seemingly, participants can relate particle motion to the kinetic molecular theory of hot and cold gas. Two subtypes were developed, as discussed below.

Type 1.1

Type 1.1 mental representation focuses on the shape of hot and cold bottles, described by some participants (n = 4; **Table 1**). They understood that hot gas particles move faster while cold particles move slower and link this to macroscopic events like a hot bottle expanding and a cold bottle denting inward. However, they struggled to connect these changes to particle size, predicting it would either increase or decrease. A key alternative conception was that hot gas particles are larger (n = 3, 10.0%; **Table 2**), similar to findings by Aslan and Demircioglu (2014), Azizoglu and Geban (2004), Lemma (2013), and Park and Light (2009). Another common error was the belief that particle size decreases during cooling (n = 3, 10.0%; **Table 2**), consistent with studies by Azizoglu and Geban (2004) and Lemma (2013). Learners often tended to attribute the macroscopic behavior of denting cold bottles to their microscopic characteristics. Interestingly, a participant has a non-scientific conception and recalled a previous science lesson, to wit:

> It will be deformed; oxygen gas goes up; what I learned about science is when the temperature becomes high, the air rises, but when the temperature becomes low, the air stays. The oxygen is on the upper part, and it will be pinched here (pointing to the lower part) It will become thinner (lower part) and bigger (pointing to the upper part) (R11) (**Figure 5**).

Hot gas accumulated on the container's upper portion, causing the bottle's lower portion to become smaller. This could be due to conceptions that hot gas in the atmosphere tends to rise while cold gas sinks.

Figure 5. Hot denting bottle (R11) (Source: Authors' own elaboration)

Figure 6. Hot denting bottle (R13) (Source: Authors' own elaboration)

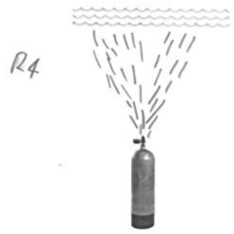


Figure 7. Lines instead of bubbles (R4) (Source: Authors' own elaboration)

For pressure effects, participants believed bubble size could increase or decrease with changes in particle motion, but their ideas about particle size were inconsistent. They described diffusion as spreading or mixing with air, thinking particle size could increase, decrease, or stay the same, while particle motion could either increase or remain constant.

Type 1.2

Type 1.2 mental representation focuses on gas diffusion mixed with air, as noted by some participants (n = 7; **Table 1**), but with varying views on particle size and motion. They understood that hot gas particles move faster and cold gas particles move slower. Some described hot bottles denting or expanding with differing views on particle size, while others thought cold bottles dented or kept the same shape. A major alternative conception in this group was the belief that hot bottles dent when heated (n = 4; 13.3%; **Table 2**). A participant reasoned that bottle shapes moved closer to each other, side to side, and particles remained below the container,

> Because the oxygen heats up, it slows down and gets heavier, pulling the shape of the bottle closer, it is congested so it's hard for it to re-surface, distance gets closer(R13) (**Figure 6**).

This could be due to the learner's experience that the bottle shape crumpled when heated, and they thought that hot gas was trapped at the bottom of the bottle.

Similarly, a participant with type 1.2 mental representation has mismatched conceptions of macro molecular events with micro molecular events, as mentioned by (R6):

> If the gas is hot, the bottle can be deformed; when the gas molecules heat up, they merge, collide, and then merge (hand compressing the bottle). Those on the sides join together, moving faster; the circle (gas particle size) grows bigger.

This could be due to confusion, a learning disability, or cognitive disequilibrium (Graesser & D'Mello, n. d.).

Participants of this group have another major alternative conception of the same bottle shape in cold gas (n = 5; 16.7%; **Table 2).** This could also be based on learners' experience with cold water, where the bottle's shape does not change, not realizing that the state of matter is different.

For pressure effects, participants gave varied descriptions and drawings of bubbles, showing increased, decreased, or mixed sizes, with some even depicting bubbles as lines. Their ideas about particle size and motion also differed, with some believing they increased, decreased, or were uncertain. No major alternative conception emerged about pressure effects, though one participant (R4) believed bubbles didn't form and instead described gas spreading, using lines to represent water movement (**Figure 7**) and stated:

> Water will get inside the tank, then air will come out. When the water gets in, it will get heavier and go to the bottom, and the gas will look like an electric fan coming out like that (pointing at the drawing). It will scatter, nothing can be seen because air/gas is not actually visible under the sea.

This participant visualized gas escaping the tank as lines, possibly influenced by cartoon illustrations. He did not realize that gas is insoluble in water and forms bubbles. Additionally, he lacked understanding of the particulate nature of matter and could not relate particles to pressure effects.

For diffusion, all participants believed that gas spreads or mixes with air. Most thought gas particles moved at the same speed as air, while a few described slower motions. They also had mixed views on particle size, describing it as smaller, larger, or unknown. A key alternative conception was that they had no clear idea of particle size during diffusion (n = 3; 10.0%; **Table 2**). As studies suggest, chemistry instruction often emphasizes macroscopic aspects, leaving learners stuck at that level (Johnstone, 1991). Even when microscopic representations are introduced through tools like ChemDraw or ChemSketch, the connection between macroscopic and microscopic phenomena may not be clearly explained.

Participants with type 1 mental representation correctly understood that a hot gas bottle expands, a cold gas bottle dents, bubbles grow as they rise, and gas diffuses. However, they struggled to connect these macroscopic events to the microscopic level, leading to alternative conceptions inconsistent with scientific concepts.

Type 2. Mental Representation

Type 2 mental representation focuses on the motion and size of hot and cold gas. Participants (n = 4; **Table 1**) understood that hot gas particles move faster with no change in particle size and cold gas particles move slower, with no change in particle size. They correctly grasped the microscopic behavior, but at the macroscopic level, they believed hot gas could expand or dent the bottle, while cold gas might expand, dent, or remain unchanged.

Some participants correctly understood that bubbles grow larger under pressure. One participant noted mixed bubble sizes. Most recognized that particle size stays the same as motion increases, though a few believed particle size increases with bubble size.

Participants correctly understood diffusion as spreading motion, but some believed gas mixed with air and followed air's motion instead of its own. One participant accurately noted that particle size stays the same during diffusion, while others thought particles would grow larger.

Participants with type 2 mental representation correctly understood that hot gas causes the bottle to expand, bubbles grow larger, and gas spreads during diffusion at the macromolecular level. However, they struggled to connect these macroscopic events with the microscopic level, though no major alternative conception was found in this group (**Table 1**).

Type 3 Mental Representation

Type 3 mental representation, seen in a few participants (n = 2; **Table 1**), showed a correct understanding that hot gas particles move faster with the same size during heating. However, they mistakenly thought particle size decreases with increased or decreased motion during cooling. Both participants believed that bottles would stay the same size for both hot and cold gas, failing to link microscopic particle behavior with macroscopic bottle behavior. Regarding pressure effects, both thought bubble size decreases and that particle size also shrinks. While one participant correctly understood that particle motion increases, the other thought it decreases. For diffusion, participants viewed it as gas mixing with air, with particles becoming smaller as the scent fades.

This indicates the lack of correct mental structure as they retrieve knowledge from LTM, but they are not considered major alternative conceptions for this group of participants (**Table 2**).

Type 4 Mental Representation

Type 4 mental representation is for motion and size of cold gas, where participants are cognizant of slower particle motion on cooling and same particle size (n = 4; **Table 1**). The following are the mental processes of this group of participants for temperature effects: cold gas will dent inwards or no change; expanding hot bottle or dent inwards; increasing, decreasing, or no idea about particle size of hot gas; increasing or same particle motion of hot gas.

For the pressure effect, all participants with type 4 mental representation believed bubbles would grow bigger. At the microscopic level, they thought particle size would either increase or stay the same, with varying ideas about particle motion, such as increasing, decreasing, or being uncertain.

Participants are cognizant that gas will spread and particle size will be the same or decrease for diffusion. They also have ideas that particle motion will decrease or increase.

This group of participants generally understood events at the macromolecular level but struggled to connect them to the micromolecular level. As a result, they had a major alternative conception that gas particle size can shrink (n = 3, 10.0%; **Table 2**) during diffusion, possibly because they associated it with a fading scent as the gas moves away.

Type 5 Mental Representation

Type 5 mental representation focuses on the motion of hot gas. Participants (n = 5; **Table 1**) correctly understood that particles move faster when heated. Most thought the hot bottle would dent inward, while others predicted it would bulge out or stay the same. A major alternative conception was that hot bottles dent inward (n = 3, 10.0%; **Table 2**), as one participant explained in his drawing.

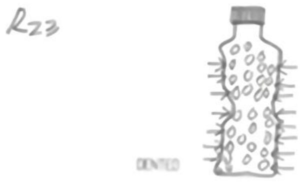


Figure 8. Hot denting bottle (R23) (Source: Authors' own elaboration)

Figure 9. Waves on pressure effect (R19) (Source: Authors' own elaboration)

> It's like being squeezed. Because when the gas heats up, the air, the pressure inside, the gas is .... like what .... will add pressure that caused being squeezed. The air inside will be compressed due to the heat pressure (pwersa). There is an arrow on the side because when heated, the things compress; the circles inside, when heated, compress until they come closer to each other, and that is what happened to the bottle (R23) (**Figure 8**).

This participant conceptualized that a hot bottle would dent inwards because of heat pressure, a conception that pressure will cause its compression; in Tagalog, "pwersa" is conceptualized as pressure/force.

At the macromolecular level, only one participant correctly thought a cold bottle would dent inward. The others believed the bottle would stay in the same shape or expand. At the micromolecular level, participants had mixed ideas about hot and cold gas particle size, thinking it could increase, decrease, or remain unknown. They also had different views on cold gas particle motion, such as not moving, increasing, staying the same, or being uncertain.

For the pressure effect, only one participant correctly thought the bubble size would increase, while others believed the bubble size would vary or decrease. At the micromolecular level, they had mixed ideas about particle size, thinking it could increase, decrease, or remain unknown. Regarding particle motion, some thought it would increase, while others believed it would decrease or stay the same.

For diffusion, all participants correctly understood that gas spreads or mixes with air. At the micromolecular level, some knew particle size stays the same, while others thought it decreases or were unsure. Most participants believed particle motion increases as gas spreads, which was a major alternative conception (n = 5, 16.6%; **Table 2**). Some participants thought particle motion decreases as the scent fades. It seems they linked particle motion to how fast or slow they smelled the perfume and associated particle size with the scent disappearing.

Type 6 Mental Representation

Type 6 mental representation focuses on the motion of hot gas and the size of cold gas. Both participants (n = 2; **Table 1**) correctly understood that hot gas particles move faster and cold gas particles are the same size. They knew that hot gas would expand the bottle, but they mistakenly believed particle size also increases with the bottle's expansion. For cold gas, they thought the bottle shape would stay the same but incorrectly believed the particles don't move, assuming the bottle's shape and particle motion are linked.

For the pressure effect, participants with type 6 mental representation thought bubble size would decrease as it rises. However, one participant described waves instead of bubbles:

> Moving, there are waves under the sea; waves will stay. Only waves can be imagined (R19) (**Figure 9**).

A participant seemed unsure about what happened to the gas from the tank and confused it with ocean waves. Both didn't understand particle motion or thought it moved sideways with the waves, while particle size either decreased or was unknown.

Participants understood diffusion as spreading or mixing with air. At the micromolecular level, they thought particle size could increase or decrease with faster particle motion. No alternative conception was found in this group (**Table 2**).

Type 7 Mental Representation

Type 7 mental representation involves demented ideas, with participants having mixed concepts about particle motion and size for hot and cold gas. This was seen in both participants (n = 2; **Table 1**) who believed hot bottles would dent inward. A participant quipped:

Figure 10. Hot denting bottle (R5) (Source: Authors' own elaboration)

Figure 11. Hot denting bottle (R22) (Source: Authors' own elaboration)

Figure 12. Gas in nature (R22) (Source: Authors' own elaboration)

> The bottle will get thinner, the air inside will disappear, it will come out because when heated, it will compress until the air disappears. Even if the bottle is closed, there will be little left inside, if it has been in the heat for a long time, the shape will change. Gas is already there, just stocked, won't move, everything is up (R5) (**Figure 10**).

The participant conceptualized that gas moving out of the container is somewhat vacuum, causing the bottle to dent inwards. Moreover, one participant mentioned:

> No visible air inside, it's like there's water inside, just air inside; the bottle shrinks, bottle compresses because it's heated, air gets closer to each other (R22) (**Figure 11**).

The participants thought there was water inside the container, possibly because of past experiences with water droplets forming during heating. He connected the hot bottle denting inward to air particles moving closer, without understanding the particulate nature of matter, as they were unaware of it from the preliminary questions.

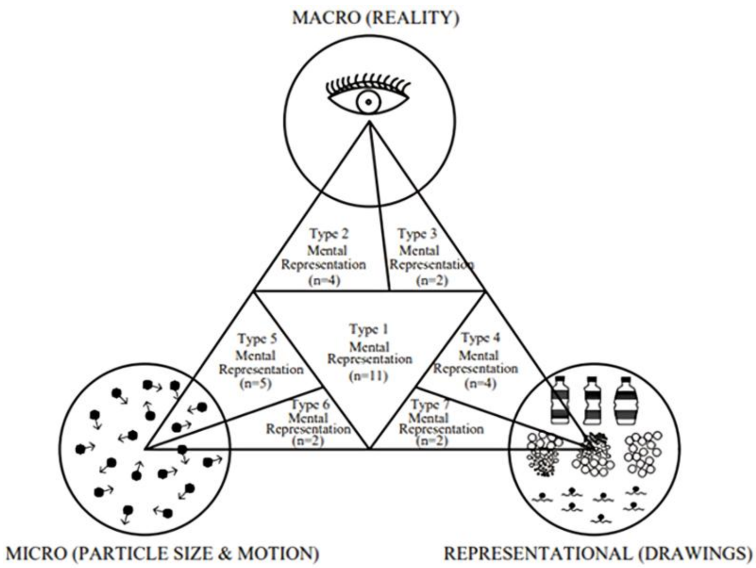
At the micromolecular level for hot gas, participants thought particles didn't change or clumped together, with no understanding of particle size. For cold gas, they predicted the bottle would expand or stay the same, with unclear ideas about particle motion and size.

A participant had confused ideas about the properties of hot and cold gas. When asked preliminary questions about gases, lines were drawn (R22) (**Figure 12**), which didn't address particle size or motion.

For the pressure effect, participants thought bubble sizes would vary as they rose, with slower particle motion and unclear ideas about particle size. They also believed gas particles mixed with air, moving slower or with the air. Although participants had confused ideas about gas behavior, no alternative conception was found for this model type (**Table 2**).

Figure 13 shows the mental representations of Filipino learners about the particulate nature of gas, influenced by temperature, pressure, and diffusion. Each corner of the triangle represents: macroscopic observations, microscopic particle motion and size, and the participants' drawings. Seven inner triangles represent different types of mental representations. The size of each triangle reflects the number of participants with that representation. Type 1 is the largest and represents the most common mental representation, while type 6 and type 7 have the fewest participants.

There is consistency in learners' responses about gas-particle motion. Type 1 to type 3 and type 5 to type 6 show that they recognize hot gas moves faster, while types 1, 2, and 4 show that they understand cold gas particles move slower. Most participants also understood that gas particle size doesn't change, whether hot or cold. However, type 7 shows inconsistencies, as participants in this group had different ideas about particle size and motion for hot and cold gas.



Legends:

Type 1 Mental Representation - Representation for Motion of Hot and Cold gas

Type 2 Mental Representation - Representation for Motion and Size of Hot and Cold Gas

Type 3 Mental Representation - Representation for Motion and Size of Hot Gas

Type 4 Mental Representation - Representation for Motion and Size of Cold Gas

Type 5 Mental Representation - Representation for Motion of Hot Gas

Type 6 Mental Representation - Representation for Motion of Hot Gas and Size of Cold Gas

Type 7 Mental Representation - Demented Representation

Figure 13. The mental representation of selected Filipino learners on gas behaviors (Source: Authors' own elaboration)

Learners understand concepts better when they can move between different chemical representations (Bodner & Domin, 2000). However, the results show that participants struggle to connect the three levels of chemical knowledge–representational, symbolic, and sub-microscopic (Johnstone, 1993; Supasorn, 2015; Talanquer, 2011). This difficulty is a major obstacle in learning gas concepts (Azizoglu & Geban, 2004). These participants also struggle with the sub-microscopic level and find the concept hard to grasp (Devetak & Glazar, 2011), often getting stuck on one level (Johnstone, 1991). Since gas particles are invisible, Filipino learners need to visualize them as particles. They tend to form surface-level understandings, which can lead to alternative conceptions. Unlike adults and experts, learners don't always visualize sub-microscopic particles correctly. Filipino learners tend to perform poorly in international assessments (Martin et al., 2015; Mullis et al., 2020), and this study may help explain the low performance. Local studies suggest Filipino learners need a unique approach to learning Chemistry due to its abstract nature (Espinosa et al., 2013). They are visual and kinesthetic learners (Magulod, 2019; Wallace, 1995), and they learn best through seeing, touching, and listening (Gacusan et al., 2023).

CONCLUSIONS

The results confirmed that many Filipino learners struggle to understand the particulate nature of matter and have difficulty connecting the three levels of chemical knowledge. They showed similar alternative conceptions about gas behavior, such as thinking particle sizes increase when heated. However, there are some alternative conceptions unique to Filipino learners, like believing hot gas dents bottles while cold gas does not change the bottle shape and not understanding particle size or changes during diffusion.

Most participants correctly understood that bubble size increases with faster particle motion, indicating that the volume increase is due to higher particle motion and related to pressure.

The study also identified seven types of mental representations among Filipino learners, with type 1 (for the motion of hot and cold gas) being the most common. These learners understand how temperature affects particle motion and size. However, they struggled to apply this understanding to gas behavior in relation to pressure and diffusion.

Overall, the results show that these learners lack understanding at the sub-microscopic level, which makes the concept difficult for them. They remain stuck at one level of understanding and cannot connect macroscopic and microscopic concepts, leading to major alternative conceptions, particularly in type 1 mental representation.

Implications, Contributions, and Recommendations

A solid understanding of the particulate nature of matter is essential to explain natural phenomena like boiling and freezing, as well as concepts in higher chemistry such as chemical bonding. In the Philippine K to 12 science curricula, the particulate nature is introduced in grade 8, where students learn about the properties of solids, liquids, and gases and the structure of substances based on particles. They are also expected to explain physical changes based on how atoms and molecules are arranged and move. By grade 10, students should understand gas behavior through gas laws and the relationship between volume, pressure, and temperature based on the kinetic molecular theory. They also classify biomolecules like carbohydrates, lipids, proteins, and nucleic acids, and apply the law of conservation of mass to chemical reactions, identifying factors that affect them.

The findings showed that most students had type 1 mental representations, meaning they understood how particle motion relates to the kinetic molecular theory, especially for hot and cold gases. However, they still had alternative conceptions about temperature's effects. For example, one participant thought the bottle's shape would shift laterally, with particles staying at the bottom. These ideas were intuitive but scientifically incorrect. It seems that students didn't fully grasp the particulate nature of matter in grade 8, and by grade 10, they couldn't explain other gas behaviors. Teachers can use observable phenomena to clarify concepts and address alternative conceptions. For example, demonstrating how air fills a container can help students understand gas particle size changes. Asking questions like, "What if gas particles grow in size? How would the container fit the same number of particles with higher temperature?" can encourage critical thinking and improve their understanding.

To improve scientific literacy, understanding students' mental representations of the particulate nature of gas can help guide updates to the K to 12 curricula. As students build their knowledge, teachers need to understand their mental representations of gas particles. These representations are key to improving teaching methods, helping students form accurate mental representations and better understand science concepts.

Findings are limited to selected Filipino learners in a particular locality that study can be conducted in several areas to represent all Filipino learners.

The study contributed to exiting literature in several ways:

(1) it bridges the gap between research and classroom practice since it offered concrete findings on students' thinking. It helps translate educational theory into practical strategies so teachers can apply them in real classrooms, thus contributing to evidence-based teaching in science education;

(2) it contributes to cognitive science and science education theory by showing how students mentally represent invisible or intangible phenomena, offering insight into the structure and development of mental representations in the domain of chemistry;

(3) it provides empirical data on how students conceptualize the particulate nature of matter that leads to alternative conceptions learners hold about gas behavior; and

(4) it effectively integrates Johnstone's (1991) chemistry triplet (macroscopic, sub-microscopic, and symbolic) by eliciting learners' drawings, verbal explanations, and interpretations of provided visuals.

This multi-level approach offers a richer understanding of how learners attempt (and struggle) to link observable phenomena with particle behavior and symbolic representations. As a result, this study broadens the application of mental representation frameworks within the field of science education research.

The findings can also contribute to improving teaching practices for learners to make sense of gas behaviour in the following ways:

1. **Using simulations of gas behavior:** Simulations model real-world processes, helping students improve their visual skills and overall learning by providing sensory experiences.
2. **Hands-on activities:** Teachers can use experiments and demonstrations, like pumping air into water to show bubble formation, to reinforce correct ideas and correct the alternative conceptions. Classroom discussions should link macroscopic and microscopic phenomena.
3. **Encouraging thought experiments:** Teachers can guide students in thought experiments, where they imagine situations, predict outcomes, and draw conclusions. This helps students process information, form abstract concepts, and correct alternative conceptions.

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