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# The Correlation Between High School Students' Visual-Spatial Ability and Their Ability to Solve Stoichiometry Problems

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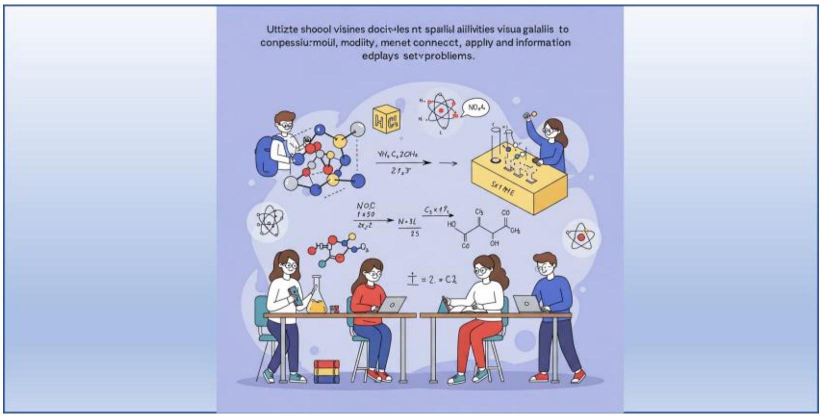
**For the past 40 years, researchers have explored the connection between visual-spatial ability and students' performance in chemistry. This study investigates whether such a relationship exists specifically in the context of stoichiometry problem-solving. A total of 70 high school students were assessed using the Purdue Visualization of Rotations Test (PVRT) and a stoichiometry test. The results show a significant positive correlation ($r = 0.341$, $p < 0.01$), with visual-spatial ability accounting for 11.6% of the variance in students' performance on stoichiometry tasks. Qualitative data from student interviews revealed that those with higher visual-spatial skills tended to use mental visualization, observe molecular interactions, and check their answers more thoroughly. These findings suggest that improving students' visual-spatial skills may enhance their ability to solve chemical problems involving multiple representations, particularly in stoichiometry.**

## Graphical abstract



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## 1. Introduction

Chemistry is a field that relies heavily on visual aids to understand and communicate concepts. A well-known example is the Thomson atomic model, often described as a "plum pudding" with electrons embedded in a positively charged sphere. Beyond such analogies, chemists utilize a variety of visual tools, including molecular models, chemical diagrams, equations, and symbolic representations, to construct and share knowledge [1]. These representations form the foundation for expanding understanding within the chemistry community.

Chemistry operates through three primary modes of representation: macroscopic, submicroscopic, and symbolic [2]. Macroscopic representations refer to phenomena that can be directly observed through the senses or their extensions.

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Submicroscopic representations are used to depict entities and processes at the particulate level—such as atoms and molecules—and are typically conveyed through diagrams or models. Symbolic representations describe chemical phenomena using symbols, formulas, and equations to communicate quantitative relationships.

Visual-spatial ability is an essential cognitive skill in learning chemistry. It allows students to interpret and transition between these representations. Prior studies have demonstrated that visualizations enhance learning, support problem-solving, and help integrate prior knowledge with new information [3]. Tasks involving chemical representations—especially at the submicroscopic and symbolic levels—require cognitive skills such as mental rotation, spatial transformation, and visual pattern recognition [4].

Psychometric research identifies various types of spatial ability, with chemistry education emphasizing three key dimensions: spatial visualization, closure flexibility, and spatial relations [4,5]. Spatial visualization involves mentally manipulating complex objects, typically assessed using the Purdue Visualization of Rotations Test (PVRT). Closure flexibility is the capacity to quickly identify visual patterns within cluttered fields, while spatial relations concern the rapid mental manipulation of simpler shapes.

Early studies found a significant correlation between spatial ability and success in general chemistry, even in areas not traditionally considered spatial, such as solving stoichiometry problems ($r = 0.32$) [6]. This raises the question of why visual-spatial ability plays a role in non-spatial topics. Some scholars, such as Cheng and Gilbert [7], argue that understanding concepts like stoichiometry involves representational conventions rather than spatial thinking. However, to solve stoichiometry problems effectively, students must interpret chemical symbols, visualize molecular-level interactions, and apply algorithmic reasoning [34].

Stoichiometry focuses on the quantitative relationships between reactants and products in chemical reactions. For example, when interpreting the balanced equation $C(s) + O_2(g) \rightarrow CO_2(g)$, students often perceive the equation as a collection of letters and numbers instead of a representation of chemical bonds breaking and forming. Chemists, in contrast, visualize this as a dynamic process involving molecular interactions. Many students struggle to connect these representations to the underlying concepts [8]. The authors hypothesize that such difficulties may stem from differences in students' visual-spatial abilities.

Chemistry learning is abstract and difficult to understand if there is no visualization of the model by developing problem-solving skills will achieve the main goal of chemistry learning [40]. Bodner [9] emphasized that successful problem solvers can use multiple representations, especially diagrams, to conceptualize and resolve problems. Representational competence—the ability to interpret and translate between different chemical representations—is critical for success in this domain [10,11,12]. When students possess strong representational competence, they can mentally transform visual inputs into internal representations that support memory, reasoning, and accurate problem-solving [13,14,15].

In line with this, previous studies have explored how representational approaches impact students' conceptual understanding. Wulandari and Rusmini [31] reported that ECIRR learning models significantly reduced students' misconceptions in stoichiometry. Elvina and Latisma [32] emphasized that students’ ability to comprehend chemical phenomena depends on their skill in interpreting multiple representations. Additionally, Cahyani et al. [33] demonstrated that visually rich media such as e-magazines can enhance students’ interest in chemistry learning, which may support better engagement with symbolic and submicroscopic concepts.

However, using correct representations does not automatically imply conceptual understanding. Expert chemists recognize patterns and draw inferences from diagrams, while novices often rely on superficial features [16,17]. Therefore, students must learn to use chemical representations thoughtfully and accurately in problem-solving contexts [18].

To solve stoichiometry problems, students must demonstrate both conceptual and procedural understanding [19]. Conceptual understanding involves interpreting phenomena through macroscopic, submicroscopic, and symbolic lenses [20], while procedural understanding relates to applying mathematical and algorithmic steps. Misconceptions often arise when students fail to connect symbolic representations with the chemical realities they describe [35].

Unfortunately, visual-spatial skills are often overlooked in science education, despite their importance in interpreting diagrams, models, and symbolic equations [21]. Mental rotation, for example, plays a role not only in visual tasks but also in constructing meaningful internal models of chemical processes. Previous studies have largely focused on college students [6,23], with fewer investigations targeting high school learners. Grabow [24] explored the link between visual-spatial skills and stoichiometry performance but did not examine the cognitive strategies used by students.

Thus, this study investigates the correlation between high school students' visual-spatial ability, as measured by PVRT, and their ability to solve stoichiometry problems. It also aims to identify the strategies students use in solving both spatial and chemical tasks. This approach addresses gaps in the literature and highlights the potential of visual-spatial skill development to improve chemistry learning outcomes [36].

## 2. Results and Discussion

The statistical results of the visual-spatial ability variable are shown in Table 1. The subjects are 70 students with a score of PVRT minimum of 2 and maximum of 18 ($M = 9.929$; $SD = 4.041$).

**Table 1.** Descriptive statistics of PVRT results, including minimum, maximum, mean, and standard deviation of visual-spatial scores among the 70 participants.

| Variable | N | Range | Mean | Std. Deviation | Minimum | Maximum |
|---|---|---|---|---|---|---|
| PVRT | 70 | 16 | 9.929 | 4.041 | 2 | 18 |

The authors categorized the data as follows: students who scored ≤ 6 were considered to have low visual-spatial ability. Those who scored between 7-13 were considered to have intermediate visual-spatial ability. Furthermore, those who scored ≥ 14 were considered to have high visual-spatial ability. As illustrated in Figure 1, the PVRT test results reveal that most students in the study (44) have intermediate visual-spatial ability. In contrast, the remaining students were evenly split between low and high visual-spatial ability.

The process of solving PVRT problems includes both cognitive activity and mental rotation. Individuals with high and intermediate levels of visual-spatial ability report that they first observe the problem, then mentally simulate rotation in their thoughts during the first and second stages and decide on the third stage. Based on interviews, it has been determined that all students solve PVRT problems in the order of the first picture, the second picture, and the third picture (see Figure 4, from top to bottom), and no students have been found to solve the problems in a back-and-forth manner.

Individuals with higher visual-spatial abilities tend to focus more on visualizing, observing, and simulating. In comparison, those with lower visual-spatial ability tend to rely more on mentally manipulating objects to solve problems with aids. This is reflected in interview responses, where individuals with lower visual-spatial ability reported using their hands to simulate rotations. Those with intermediate visual-spatial abilities did in between. In the third picture, students with high and low visual-spatial ability make choices and comparison options. However, those with higher visual-spatial ability were observed to compare the position of the object at the beginning and the end, while the students with intermediate and lower visual-spatial ability did not.

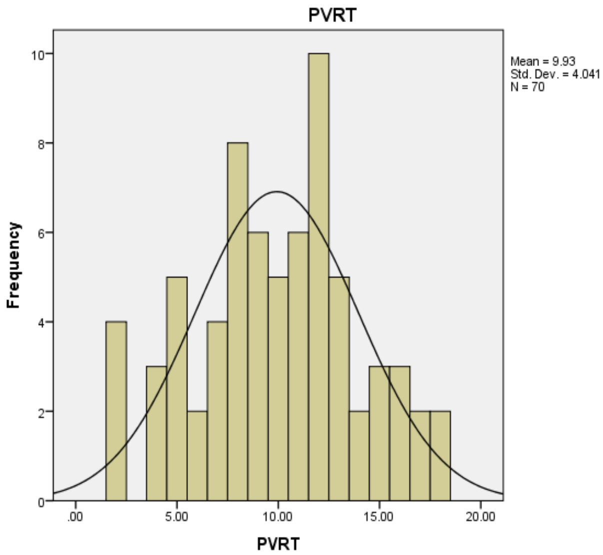



**Fig. 1.** Distribution of PVRT scores among 70 high school students. The bar chart shows the frequency of students falling within low, intermediate, and high visual-spatial ability categories.

**Table 2.** Sample student responses from the PVRT interview. This table categorizes the mental strategies used to solve mental rotation problems according to the students' visual-spatial ability levels.

| Question: "How did you solve this problem?" | | |
|---|---|---|
| **Spatial Visual Ability Level** | **Answers** | **Results** |
| High | I imagined how the part of the box would be if I rotated it. I observed the shape of the plane, then I rotated it. | Visualization, observing, simulating rotation in mind |
| | I rotated it like the first so that this small plane was not visible. I didn't observe the angle. I observed it from the plane just to be sure. | Simulating rotation in mind, observing |
| | This is an example of this (showing the first picture). When it is rotated backward, it becomes like that (showing the second picture), following the hands going around. If what was originally reversed like this, the end is also reversed like this. It depends on the opposite (plane). | Observing, simulating rotation in mind, rotating with aids, comparing item options |
| Intermediate | I observe the plane and how it rotates. | Observing, simulating rotation in mind |
| | I observe the plane that appears, then I rotate it (rotating with hand). | Observing, simulating rotation in mind, rotating with aids |
| | I observe from the plane then the rotation. | Observing, simulating rotation in mind |
| | I observed the top. So, if the top is here, the bottom must also move here. I observed the unique plane. | Observing |
| Low | Initially it's rotated once following the initial. The lower ones are also rotated (using hand). | Simulating rotation in mind, rotating with aids |
| | Logically, if it's like this, it means that another quarter circle is then rotated. Another way is that I twist my body. | Simulating rotation in mind, rotating with aids |
| | If it's like this, turn it to the right side. In the example, it is rotated to the right. This means this one is also rotated to the right (using hand). | Simulating rotation in mind, rotating with aids |

**Table 3.** Summary of PVRT problem-solving strategies. It presents the common cognitive approaches employed by students with high, intermediate, and low spatial skills.

| Spatial Visual Ability | Strategy Used |
|---|---|
| High | Visualization, observing, simulating rotation in mind, rotating with aids, comparing item options |
| Intermediate | Observing, simulating rotation in mind, rotating with aids |
| Low | Simulating rotation in mind, rotating with aids |

Table 4 and Figure 2 displays the means and standard deviation for the ability in solving stoichiometry problems. The subjects are 70 students with a score of stoichiometry test minimum of 0.5 and maximum of 20 (M = 9.193; SD = 5.146).

**Table 4.** Descriptive statistics of stoichiometry test scores. The table summarizes the performance of students in solving stoichiometry problems, including score ranges and central tendencies.

| Variable | N | Range | Mean | Std. Deviation | Minimum | Maximum |
|---|---|---|---|---|---|---|
| Stoichiometry | 70 | 19.5 | 9.193 | 5.146 | 0.5 | 20 |

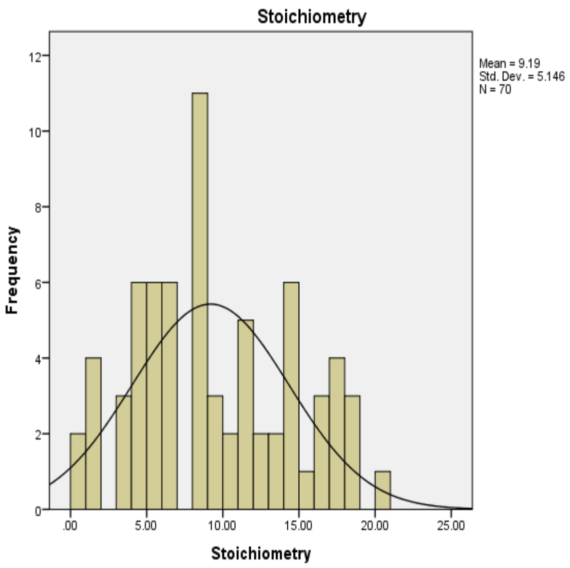



**Fig. 2.** Distribution of stoichiometry test scores. This histogram displays the performance levels of students on stoichiometric problem-solving tasks.

The results of the Pearson correlation analysis (Table 5. and Figure 3.) show that there is a significant relationship between PVRT and stoichiometry test result with r = 0.341; p<.001. It means that the null hypothesis is rejected, and the alternative hypothesis is accepted. This suggests a relationship between visual-spatial ability and students' ability to solve stoichiometry problems. The data also reveals that the visual-spatial ability variable accounts for 11.6% of the variance in students' stoichiometry problem-solving ability. The p-value of Shapiro-Wilk, 0.346 or significant (sig> 0.05), shows that the data is distributed normally.

Table 6 demonstrates the proficiency of students in solving stoichiometry problems. Question 2 on the test was the easiest for students, while question 7 was the most challenging. Questions 5 and 7, which incorporate numerical concepts, presented difficulty for students. Conversely, questions 2, 6B, and 6A, which focus on symbolic concepts, were the least challenging.

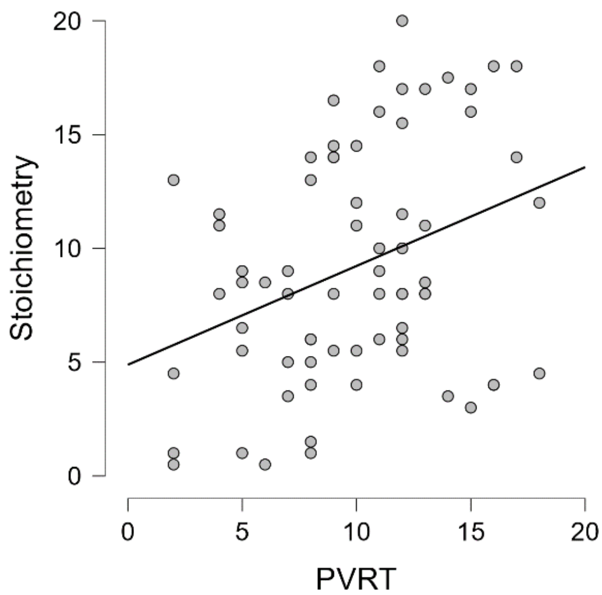



**Fig. 3.** Scatter plot showing the correlation between PVRT and stoichiometry test results. A trend line illustrates the positive linear relationship (r = 0.341, p < 0.01).

**Table 5.** Correlation analysis between PVRT and stoichiometry test results. It shows Pearson's r, p-value, and the Shapiro-Wilk test to assess normality and significance.

| Pearson's Correlations | | | | Shapiro-Wilk Test for Bivariate Normality | | |
|---|---|---|---|---|---|---|
| | n | Pearson's r | p | | Shapiro-Wilk | p |
| PVRT - Stoichiometry | 70 | 0.341** | 0.002 | PVRT - Stoichiometry | 0.980 | 0.346 |

Note. All tests one-tailed, for positive correlation. * p < .05, ** p < .01, *** p < .001, one-tailed.

The study found that the easiest-hardest for the sample is symbolic-submicroscopic-symbolic-numeric. The questions involving symbolic representation (question 2) came earlier than expected, followed by questions involving submicroscopic representation (questions 6B, 6A, 1A, 4A, 1B, and 4B). The questions requiring numerical problem-solving skills (numbers 5 and 7) appeared last, as predicted. We found question 3, which should be the foundation of higher concepts, comes much later. We outline problem-solving techniques in stoichiometry problems varying from students' answers.

**Table 6.** Number of students who answered each stoichiometry question correctly. It helps identify which problems were easiest and most difficult.

| Question code | 2 | 6B | 6A | 1A | 4A | 1B | 4B | 3 | 5 | 7 |
|---|---|---|---|---|---|---|---|---|---|---|
| Number of students with correct answer | 62 | 60 | 56 | 49 | 44 | 38 | 32 | 27 | 18 | 15 |

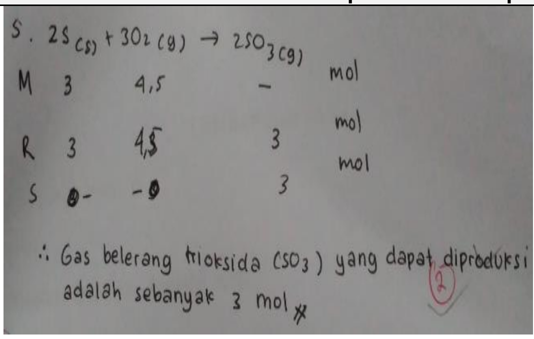
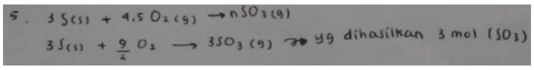
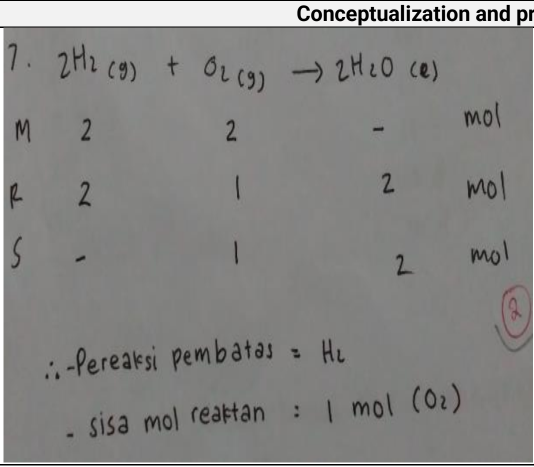
Students are expected to answer the questions in this order (according to the complexity): 1A-1B-3-6A-6B-2-4A-4B-5-7.

**Table 7.** Excerpts from student interviews on stoichiometry test items. Responses are analyzed based on the degree of correctness and understanding of chemical representations.

| Question: "How did you solve this problem?" | | | |
|---|---|---|---|
| **No** | **Type of Answer** | **Answer** | **Result** |
| **Sub-microscopic representation of molecules-uni molecules** | | | |
| 1A | Correct | First, I look at the picture, count the bonded atoms, and count the number of molecules present. There are six molecules composed of three H atoms and one N atom. | Understand the sub-microscopic representation, change the information obtained into symbolic representation, and apply the writing rules |
| | Partially correct | In the picture, there are N atoms and H atoms. One N atom bonds with three H atoms, so the answer is $NH_3$. | Understand the sub-microscopic representation, change the information obtained into symbolic representation, and apply the writing rules, but miss the number of molecules shown |
| | Incorrect with misconception | In the picture, there are N atoms and H atoms. N molecules bond with three H atoms to form $NH_3$. There are six molecules, so the answer is $(NH_3)_6$. | Understand the sub-microscopic representation, and change the information obtained into symbolic representation, but do not apply the writing rules |
| | Incorrect | I write down the number of atoms. The picture has six black circles and 18 white circles, so the answer is $N_6H_{18}$. | See the sub-microscopic representation but do not understand the concept |
| **Sub-microscopic representation of molecules-different molecules** | | | |
| 1B | Correct | First, I look at the picture, count the bonded atoms, and count the number of molecules present. There are five molecules consisting of one molecule of $N_2$; the N atom is covalently bonded to another N atom. In one $H_2$ molecule, the H atoms are covalently bonded to another H atom. And three molecules of $NH_3$, one N atom bonds with three H atoms. | Understand the sub-microscopic representation, change the information obtained into symbolic representation, and apply the writing rules |
| | Partially correct | There are three N (in which each of them) that bonds to H. There are also three H that bonds to one N. I ignore the others. | Understand the sub-microscopic representation, change the information obtained into symbolic representation, and apply the writing rules, but miss number of molecules is shown |
| | Incorrect with misconception. | In the picture, there is an N molecule and an H molecule. N molecule bonds with 3 H molecules to form $NH_3$. There are 3 molecules, so the answer is $(NH_3)_3$. | Understand the sub-microscopic representation, and change the information obtained into symbolic representation, but do not apply the writing rules |
| | Incorrect | I write down the number of atoms. The picture has five black circles and 11 white circles, so the answer is $N_5H_{11}$. I ignore the image's shape. | See the sub-microscopic representation but do not understand the concept |
| **Symbolic representation of chemical reaction** | | | |
| 2 | Correct | Hydrogen gas reacts with nitrogen gas to produce $NH_3$ gas. Then it is | Understand the symbolic representation, can |

| | | | |
|---|---|---|---|
| | | equalized to 1/2 mole of $N_2$ gas, reacting with 3/2 mole of $H_2$ gas to make one mole of $NH_3$ gas. To keep it from being a fraction, I multiply by 2 to get $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$. | manipulate the information, and apply the writing rules |
| | Partially correct | So first, I write down $N_2 + H_2$ to produce the $NH_3$ product. Then the product is balanced so that it becomes $1/2N_2(g) + 3/2H_2(g) \rightarrow NH_3(g)$. | Understand the symbolic representation, can manipulate the information, and partially apply the writing rules |
| | Incorrect with misconception | So first, I write down $N_2 + H_2$ to produce the $NH_3$ product. Then balance it so that it becomes $N_2(g) + (H_2)_3(g) \rightarrow (NH_3)_2(g)$. | Understand the symbolic representation, can manipulate the information, but not apply the writing rules |
| | Incorrect, | I think about how $NH_3$ is formed. I don't see the constituents. So, I write $N(g) + 3H(g) \rightarrow NH_3(g)$. | Do not understand the symbolic representation and cannot manipulate the information |
| **Symbolic representation of molecules** | | | |
| 3 | Correct | The coefficient indicates the number of molecules. Subscribe shows the number of bonded atoms. So that $3N_2$, 2 suggests that there are two bonded N atoms, and 3 indicates that there are three $N_2$ molecules. | Understand the symbolic representation and can change the information obtained into sub-microscopic representation. |
| | Partially correct | The coefficient indicates the number of atoms in the molecule. 3 shows the number of $N_2$ molecules. Then the subscript does not know because it has never been taught. | Partially understand the symbolic representation and can change the information obtained into sub-microscopic representation |
| | Incorrect with misconception | The coefficients indicate the number of molecules, while the subscripts indicate the charge and are fixed. Usually, if the subscript is 2, it's gas. So that in $3N_2$, there are 3 molecules of $N_2$, and it is a gas. | Misunderstand the meaning of coefficients |
| | Incorrect | The volume is equal to the molecular coefficient. While the subscript is similar to the number of bonds. | Do not understand the symbolic representation of molecules |
| **Sub-microscopic and symbolic representation of chemical reaction** | | | |
| 4A | Correct | Because the reaction produces $SO_3$, each sulphur atom is paired with three O atoms to form $SO_3$. Since there are six S atoms and nine $O_2$ molecules when paired, it turns out that there are O atoms, and there is no residue to produce $6SO_3$. | Understand the representation at symbolic levels, connect, and use information obtained into sub-microscopic representation |
| | Partially correct. | There are five sulphur molecules and six $O_2$ molecules, which then react to produce five $SO_3$ molecules. I observe it from the S alone because the coefficient of S is the same as $SO_3$, so the result is $5SO_3$. | Understand the representation at symbolic levels, connect, and use information obtained into sub-microscopic representation, but miss the number of molecules shown |
| | Incorrect with misconception | First, look at the reaction and then look at the picture. The reaction produces $2SO_3$. $O_2$ can't be separated, so to form $SO_3$, there must be two bonds, which means joining. So, it starts like this (shows the picture) and reads $2SO_3$. | Understand the representation at symbolic levels, connect, and use information obtained into sub-microscopic representation, but misunderstand the meaning of coefficients and subscripts |
| | Incorrect | I didn't understand, so I wrote down a picture of the equation for the reaction so that there are two S, three $O_2$, and two $SO_3$. | Do not understand the sub-microscopic representations, cannot connect different representations |
| **Sub-microscopic and symbolic representation of limiting reagent** | | | |
| 4B | Correct | Because it produces $SO_3$, each S atom | Understand the |

| | | | |
|---|---|---|---|
| | | is paired with three O atoms, $SO_3$ is sufficient. Different from question 4A, in question 4B, there are residues. When reacted, the amount of S is excess, so the product is not only $SO_3$ but also S atoms left. | representation at symbolic levels, connect, and use information obtained into sub-microscopic representation |
| | Partially correct | There are five sulphur molecules and six $O_2$ molecules, which then react to produce five $SO_3$ molecules. I observe it from the S alone because the coefficient of S is the same as $SO_3$. | Understand the representation at symbolic levels, connect, and use information obtained into sub-microscopic representation, but miss number of molecules shown |
| | Incorrect with misconception | First, I look at the reaction, then look at the picture. The reaction produces $2SO_3$. $O_2$ can't be separated, so to form $SO_3$, two bonds must be joined, so it starts like this (see table), so it reads $2SO_3$. The difference is from question 4A, some don't get a partner, so they are alone. | Understand the representation at symbolic levels, connect, and use information obtained into sub-microscopic representation, but misunderstand the meaning of coefficients and subscripts |
| | Incorrect | I don't understand, sir. So, I wrote down a picture of the reaction equation, sir. So, I paired the S with two O's to make it even. | Do not understand the sub-microscopic representations, cannot connect different representations |
| **Sub-microscopic representation of chemical reaction** | | | |
| 6A | Correct | Three molecules of chlorine gas react with three molecules of hydrogen gas to produce six molecules of HCl gas. An equal reaction is not based on the number of molecules involved. Still, it is the simplest comparison of the number of molecules in the reaction. The picture is just an application of the balanced reaction equation, so I choose (e) $Cl_2(g) + H_2(g) \rightarrow 2HCl(g)$. | Understand the representation at sub-microscopic levels, connect, and use information obtained into symbolic representation, and understand the writing rules |
| | Partially correct | There are three molecules with gas $H_2$ and three $Cl_2$ molecules, which have all reacted. Because it reacts, the $Cl_2$ molecules that were previously paired break down. $H_2$ also breaks down and then unites to become HCl. Because there are three $Cl_2$ molecules and three $H_2$ molecules, when they react, they run out to become six HCl. | Understand the representation at sub-microscopic levels, connect, and use information obtained into symbolic representation, but partially understand the writing rules |
| | Incorrect with misconception | I chose answer (b) $6Cl(g) + 6H(g) \rightarrow 6HCl(g)$ because it fits the picture. The amount of substance on the left and right is the same. | Not understand the representation at sub-microscopic levels and not understand the writing rules |
| **Sub-microscopic representation of limiting reagent** | | | |
| 6B | Correct | Different from question 6A, in question 6B, there are excess. The balanced reaction is not based on the number of molecules involved. Still, it is the simplest ratio of the number of molecules in the reaction. To answer, I use the direct reaction equation. One molecule of hydrogen gas reacts with half a molecule of oxygen gas to produce one molecule of water. Then I multiply by two to get rid of the fraction. The drawing is just an application of the balanced reaction equation. | Understand the representation at sub-microscopic levels, connect, and use information obtained into symbolic representation, and understand the writing rules |
| | Partially correct. | The difference is with question 6A; if the H atoms and Cl atoms are all bonded, in question 6B, they are not. There are still unbonded H atoms, so not all of them bond with O atoms and | Understand the representation at sub-microscopic levels, connect, and use information obtained into |

| | | | |
|---|---|---|---|
| | | form $H_2O$. There are six molecules of $H_2$ and two molecules of $O_2$. If it bonds to produce $H_2O$, it requires two atoms of H and one atom of O. If there are four O, only eight H is needed, while in the picture, there are twelve H atoms meaning the remaining four are not used. | symbolic representation, but partially understand the writing rules |
| | Incorrect with misconception | I chose the answer (b) $(O_2)_2(g)$ + $(H_2)_4(g) \rightarrow (H_2O)_4(l) + (H_2)_2(g)$ because it fits the picture. The amount of substance on the left and right is the same. | Not understand the representation at sub-microscopic levels and not understand the writing rules |
| **Conceptualization and problem-solving of chemical reaction** | | | |
| 5 |  | First, the reaction equation is balanced. Because it is equivalent, I immediately wrote. And at first, there were 3 moles of sulphur and 4.5 moles of oxygen gas then I entered them into the MRS (Initial-Change-Final) table. The reaction went perfectly. Nothing acts as a limiting reagent, so 3 moles of sulphur react with 4.5 moles of oxygen gas to produce 3 moles of $SO_3$. | Understand the representation at symbolic levels, connect, use information obtained to solve numeric problem, and check whether the answer is in line with the representation |
| |  | Because the product and reactant coefficients are the same, I equate the number of moles of $SO_3$ with the number of moles. | Understand the representation at symbolic levels, connect, use information obtained to solve numeric problem |
| **Conceptualization and problem-solving of limiting reagent** | | | |
| 7 |  | First, the chemical equation is balanced to produce $O_2(g) + 2H_2(g) \rightarrow 2H_2O(l)$. And initially, there were two moles of hydrogen gas and two moles of oxygen gas. What runs out first is the limiting reagent. The one that runs out first has the largest coefficient. If hydrogen is used up first, hydrogen is the limiting reagent. So, 2 moles of hydrogen gas react with 1 mole of oxygen gas to produce 2 moles of $H_2O$. Since the coefficient of $H_2O$ is 2, the remaining mole of $O_2$ is 1 mole. | Understand the representation at symbolic levels, connect, use information obtained to solve numeric problem, and check whether the answer is in line with the representation |

Based on Table 7, individuals with correct answers tend to understand the representation (at sub-microscopic or symbolic levels), change the information into another representation, connect, use information obtained to solve (numeric) problems, and check whether the answer is in line with the representation and writing rules. Individuals with partially correct answers tend to do the same; however, they do not check or miss whether the answer is in line with the representation and writing rules. Students with incorrect answers with misconceptions tend to observe, change, connect, and use the information but misunderstand the meaning behind representation and writing rules. They tend to develop their understanding of representation differing from chemical concepts. On the other hand, students with incorrect answers only tend not to understand the representation or concept behind representation or not be able to connect different representations or not understand the writing rules.

Students are expected to answer the questions in this order (according to the questions' complexity): 1A-1B-3-6A-6B-2-4A-4B-5-7. However, students found question 2 to be the easiest and question 7 to be the most challenging. Both questions pertained to a chemical reaction, but question 2 only dealt with a symbolic approach, while question 7 detailed numerical calculations. According to the research of Arasasingham et al. [25], students new to problem-solving in stoichiometry typically approach problems using a symbolic representation, then an algorithmic method, and finally, a visualization technique. This partially explains why question 2, which deals with a symbolic representation of a chemical reaction, is the easiest, and questions with sub-microscopic representation and numeric problem-solving come later.

The questions involving visual and molecular perspectives, specifically 6B, 6A, 1A, 4A, 1B, and 4B, were found in a sequence after those involving symbolic perspectives. This implies that students' performance on these questions may have been similar due to the need to utilize the visual molecular perspective. This order of difficulty, as found by Arasasingham et al. [25] for college chemistry students, may also apply to high school students, and it would be worth further study. Additionally, the significant correlations between all these questions indicate that visual-spatial ability is only one aspect of many involved when solving stoichiometric problems. It may be related to formal reasoning skills that were not specifically measured in this study.

The students had difficulty with questions 5 and 7, which both required a numerical perspective. This indicates that students have difficulty with understanding and applying numeric perspectives. They may find it challenging to solve problems that require them to understand chemical phenomena, connect different representations, make changes, and transfer knowledge and skills, not just simply move among different representations [37].

What surprised us was question 3 (a symbolic representation of molecules), which comes just before 5 and 7. Understanding the coefficient and subscription in a chemical formula is the foundation of chemistry. The inability to understand and explain those can lead to misconceptions [38]. Still, students may be able to solve the stoichiometry problem by memorizing steps as mathematics equations, but this will lead to failure to understand the chemical concept behind the symbolic representation of molecules [39].

This study found evidence supporting that students who performed well on the PVRT tend to perform well on stoichiometry problem-solving tests and vice versa. This indicates that students with higher visual-spatial abilities are more likely to be successful when solving stoichiometry problems than those with lower visual-spatial abilities. This correlation is not a coincidence; visual-spatial abilities are necessary for solving stoichiometry problems. This is supported by previous research conducted by Bodner & McMillen [6] and Bodner et al. [23] in college-level settings as well as Grabow [24] in high-school-level settings.

We found a link between the abilities to solve PVRT and stoichiometry problems. Based on interviews, individuals who are better at visual-spatial tasks tend to rely more on observing, visualizing, and simulating in their minds to solve problems. In contrast, those less skilled in these tasks have problems with one (or more) of those strategies and thus tend to use their hands and other tools to manipulate objects to find solutions. In addition, those with intermediate abilities fall somewhere in between. The primary strategy to solve PVRT is observing, visualizing, and simulating the rotation in mind.

Our findings in the stoichiometry test are consistent with the idea that students who got the correct answers could comprehend the information by observing the representation, visualizing and transforming it into another representation, simulating connections between representations, and using the obtained information to solve numerical problems [25]. It is important to observe, visualize, and simulate the representation in mind of stoichiometry problems to solve them. The authors related this finding to students' mastery of representational competence. There is a significant correlation between conceptual understanding and chemical representation on stoichiometry [26] and chemical equilibrium [27].

Students who struggle with stoichiometry often have difficulty understanding the meaning behind the representation and connecting it to the underlying chemical concepts. They tend to develop their understanding of representation boundless to chemical concepts. Another factor that hinders students who perform poorly is that they misunderstand or do not even understand chemistry writing rules. Therefore, observing, understanding, connecting representations, and mentally simulating are crucial skills for understanding and solving PVRT and stoichiometry problems.

An effective strategy for solving PVRT and stoichiometry is analyzing how information is presented. In the case of PVRT, students with high visual-spatial skills were found to compare the position of objects at the beginning and end. In contrast, those with weaker visual-spatial skills did not. Similarly, in stoichiometry tests, students who performed well were observed to carefully check if their answers adhered to the representation and writing rules. Verifying answers is essential because people with partially correct answers may perform just as well as those with correct answers. However, they may need to verify or realize that their answers are not following the representations and writing rules.

Students with strong visual-spatial abilities but need a deeper understanding of the concept tend to provide inaccurate answers when describing a given representation. Instead of writing the correct equation, $Cl2(g) + H2(g) \rightarrow 2HCl(g)$, they may write $6Cl(g) + 6H(g) \rightarrow 6HCl(g)$. The authors attribute this problem to alternate conceptions, which are ideas that conflict with the accepted scientific understanding [28]. These alternate conceptions may stem from the student's intuition or incomplete knowledge. In this case, the student may assume that the arrows in chemical equations only indicate that the number of atoms on each side must match rather than represent actual chemical processes [29].

In previous research conducted examining the link between spatial thinking and success in problem-solving [30], it was determined that spatial ability appears to play a significant role in the problem conception stage, particularly for word problems. High levels of spatial ability enabled students to translate words into equations that could subsequently be solved. This can be seen from the interview for questions 5 and 7, where students who can solve the problems understand the problems by balancing the chemical reactions before going to the next mathematical operational steps. Failing to understand these steps (problem conceptions) will lead to failing the algorithmic operations.

Word problems that lack clear visuals in their description demand the use of visual-spatial abilities to visualize and solve them. This can be cognitively demanding, and individuals with solid visual-spatial abilities are better equipped to handle these challenges. To foster excellent scientists in the future, we should implement research on spatial cognition in educational practices to help students improve their verbal, mathematical, and visual-spatial abilities. This will likely result in improved performance in various tasks that require visualization and the ability to think creatively and form mental images from complex or vague problem descriptions.

Research on the correlation between spatial ability and problem-solving in first-year engineering students also showed that aside from having a substantial and significant effect on success in representation, the visual-spatial ability has no connection to mathematical abilities during the solution phase [30]. Students with limited spatial ability were more prone to mistakes in translating tasks and relational statements and choosing the correct schema for a problem. However, they found that there was no variance in mathematical ability (needed for solving the problems) between students with low and high spatial ability. This is in line with what we found where 42 students in question no 5 and 32 students in question no 7 can only conceptualize the problems without being able to solve the mathematical problems.

## 3. Material and Methods

This research used a quantitative descriptive approach. The subjects of the study were 12th-grade students from two private senior high schools at Malang, East Java, Indonesia, totaling 70 students. To measure students' visual-spatial ability, subjects were given the PVRT test developed by Bodner and Guay [22]. The participants received 1 point for each correct answer and no points for incorrect answers, resulting in a total score of 20, and given 15 minutes to complete 20 questions. Despite the 3D nature of the test items, they were displayed on 2D papeer.

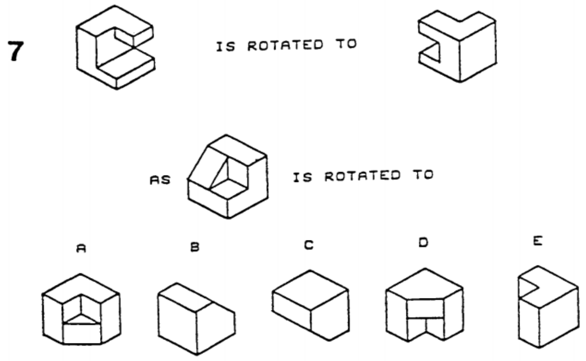



**Fig. 4.** Sample item from the PVRT (adapted from Wu & Shah, 2003), showing a 3D object that must be mentally rotated to determine the correct orientation among multiple-choice options.

To measure the stoichiometry problem-solving ability, the students were given 45 minutes to complete ten questions. The participants received 1 - 4 points for each correct answer (depending on difficulty) and no points for incorrect answers, resulting in a total score of 20. The question codes and type of information are listed in Table 8.

**Table 8.** Classification of test questions by type of chemical representation involved (e.g., symbolic, submicroscopic). It provides context for the structure of the stoichiometry assessment.

| Question code | Test information |
|---|---|
| 1A | Sub-microscopic representation of molecules-uni molecules |
| 1B | Sub-microscopic representation of molecules-different molecules |
| 2 | Symbolic representation of chemical reaction |
| 3 | Symbolic representation of molecules |
| 4A | Sub-microscopic and symbolic representation of chemical reaction |
| 4B | Sub-microscopic and symbolic representation of limiting reagent |
| 5 | Conceptualization and problem-solving of chemical reaction |
| 6A | Sub-microscopic representation of chemical reaction |
| 6B | Sub-microscopic representation of limiting reagent |
| 7 | Conceptualization and problem-solving of limiting reagent |

The problems selected are stoichiometry topics, and solving them requires a thorough understanding of representations, as per the test information. It is worth mentioning that the questions are not arranged in order of hierarchy, despite their numerical sequence.

The data analysis includes statistical analysis: (1) normality test using Shapiro-Wilk and (2) parametric statistical hypothesis test using Pearson product-moment correlation. An interview was performed to clarify the students' answers and their understanding. The hypotheses of this study are

H0: There is no positive correlation between high school students' PVRT and stoichiometry test results.

H1: There is a positive correlation between high school students' PVRT and stoichiometry test results.

By conducting interviews or collecting information through open-ended questions, authors could thoroughly comprehend students' cognitive process utilized in solving PVRT and stoichiometry problems. 10 participants underwent recorded interviews where they were asked the main question: "How did you solve this problem?" The interview answers were analyzed through content analysis to extract the cognitive strategies used by the participants, which were either stated directly or deduced from the surrounding information. The authors jointly conducted the open coding analysis.

## 4. Conclusions

This study provides evidence of a statistically significant positive correlation between high school students' visual-spatial ability and their ability to solve stoichiometry problems ($r = 0.341$, $p < 0.01$). Students with stronger visual-spatial skills tend to better interpret representations, transform them into different formats, and apply conceptual and procedural knowledge to solve problems accurately. These findings highlight the importance of representational competence in chemistry learning and suggest that enhancing students' visual-spatial skills may support their success in topics requiring the integration of macroscopic, submicroscopic, symbolic, and numeric representations.

Limitations of this study include the relatively small and geographically limited sample, as well as the focus on only one cognitive domain. Future research should consider broader populations and explore other influencing factors such as logical-mathematical reasoning, prior knowledge, or metacognitive skills. Interventions designed to strengthen students' visual-spatial skills and their ability to navigate representational systems could be beneficial in improving conceptual understanding and problem-solving performance in chemistry.

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## Author Contributions

Herunata: conceptualization, methodology, formal analysis, writing-original draft. Anugrah Ricky Wijaya: conceptualization, methodology, formal analysis, resources, writing-original draft, supervision, project administration and funding acquisition. Muhammad Zainur Rifai: conceptualization, resources, writing-original draft, supervision, project administration and funding acquisition. Deni Ainur Rokhim: conceptualization, resources, writing-original draft, supervision, project administration and funding acquisition.

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