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Drawing Coupled with Feedback:
Effects on Filipino Senior High School Students'
Submicroscopic Understanding of Chemical Reactions

A thesis
submitted in fulfilment
of the requirements for the Degree
of
Doctor of Philosophy in Science and Technology Education
at
The University of Waikato
by
GARRY DASIG GALVEZ



THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

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Dedication

This humble achievement is dedicated to two wonderful human beings,
my grandfather, lolo Erning Galvez[†] and to the love of my life, Rio B. Lagahit.

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G.D.G

Abstract

Understanding a chemical phenomenon across the macroscopic, submicroscopic and symbolic domains (chemistry triplet) is the central tenet of chemistry thinking (Talanquer, 2018). This study utilised drawing as a potential tool to cultivate students' understanding of the chemistry triplet (Johnstone, 1997) in learning chemical reactions. In drawing reactions, some are easier than others depending on whether they involved atoms and/or molecules only, or ions. However, it is not clear why difficulty in drawing reactions involving ions differs. To address this, my study investigated how teacher-feedback and peer-feedback, two common sources of feedback in classroom teaching, affected students' drawings of different reactions at the submicroscopic level. A two-group quasi-experimental research design was used. Two Grade 11 (~17 years old) General Chemistry classes from a public laboratory high school in the Philippines received either teacher-feedback (50 students) or peer-feedback (51 students). The students in both groups performed a series of practical work on the four types of chemical reactions (i.e., combination, decomposition, single displacement, and double displacement), drew freehand their submicroscopic understanding of these reactions, received feedback and revised their drawings. The ICAP theory (Chi, 2021, 2009; Chi & Wylie, 2014) was applied to characterise student engagement with the feedback source. Based on the theory, teacher-feedback was regarded as *active* learning and peer-feedback as *interactive* learning. A month after the intervention, students' learning outcomes in terms of recall and transfer were assessed.

Students' drawings were analysed using a visual-spatial scoring rubric. The findings showed that the difficulty of drawings reactions did not depend on the reaction types but on the identity of the chemical species involved, specifically the features of the ionic species. Also, quantitative results demonstrated that teacher-feedback supported students to produce higher quality of drawings than peer-feedback, particularly for the more challenging reactions, i.e., involving identity transformation (atoms and/or molecules becoming ions or vice versa). The

delivery of teacher-feedback during whole-class presentation and peer-feedback during in-group discussion was audiotaped and videotaped. The feedback dialogues were analysed using an iterative cycle of deductive and inductive analysis. Qualitative results demonstrated that the two feedback sources exhibited distinct categories of *feedback foci* and *feedback moves*. These categories explicated feedback features beneficial for supporting drawing to learn for large classes. These features include adequate level of conceptual knowledge of the feedback provider, use of explanations and posing questions as productive *feedback moves*, and *active* student engagement with feedback. The findings of my study offer a suggestion on how to sequence progressively the teaching of different types of chemical reactions.

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Chapter 1 Introduction

1.1 Background of the Study

In chemistry, concepts are represented between the macroscopic, submicroscopic, and symbolic domains (Johnstone, 1997). The macroscopic domain refers to the observable and perceptible phenomena. The submicroscopic domain refers to the structure and behaviour of submicroscopic entities like atoms, molecules, ions, and subatomic particles that determine the macroscopic phenomena. The symbolic domain refers to the signs and symbols used to represent the macroscopic domain and/or the submicroscopic entities and processes (Taber, 2019b). The relationship between these three domains is collectively referred to as the triplet relationship (Gilbert & Treagust, 2009) or chemistry triplet (Taber, 2019b). The triplet relationship is linked to structure-property reasoning (Talanquer, 2018). Structure-property reasoning is based on the idea that chemical and physical properties of substances in the world are determined by their composition, i.e., the structure and behaviour of the submicroscopic entities (Talanquer, 2018). Understanding the triplet relationship and structure-property reasoning is the central tenet of chemical thinking (Talanquer, 2018). Yet for students of chemistry moving between the three domains, in particular linking submicroscopic understanding with the symbolic representation and macroscopic phenomena remains a challenge (Taber, 2018a). Students need assistance to help them develop such an ability (Taber, 2018a).

As a science and chemistry teacher in the Philippines for nine years, I have observed that students struggle with linking the three domains of the chemistry triplet. Explaining the properties of substances based on the structure and behaviour of its composition was a challenge for students. Most students were fascinated by macroscopic phenomena observed during practical work. Examples include colour changes and gas evolution during chemical reactions, and the production of different flame colours during a flame test. Yet students

struggled to give scientific submicroscopic explanations for these observed phenomena. Students also wrote chemical symbols and formulae, balanced chemical equations and performed chemical calculations (although most of them struggled) without offering submicroscopic explanations and linking them to macroscopic observations.

I have also been a chemistry teacher-trainer in the Philippines for many years and I had different observations with teachers. Chemistry teachers were fascinated by macroscopic phenomena during practical work. Yet most of the teachers I worked with rarely used practical work in their teaching. Unlike students, chemistry teachers readily wrote chemical symbols and formulae, balanced chemical equations and performed chemical calculations. When prompted, chemistry teachers (who are domain knowledge experts) offered submicroscopic explanations for the observed macroscopic phenomena and symbolic representations. Nonetheless, during their teaching, chemistry teachers rarely made explicit how the domains of the chemistry triplet relate to each other. These three domains were often taught as if they are distinct and disconnected ideas. In addition to the challenge is the class size. In the Philippines, the average class size for secondary schools is 50 students. This class size is more crowded compared to other Asian countries, i.e., Malaysia is 34, Thailand is 42, Japan is 34 and India is 39 (Class Size and Conditions Act, 2022).

From this standpoint, I wanted to devise a way to assist chemistry teachers in cultivating students' understanding of the triplet relationship in their classrooms. It is vital that students explicitly recognise how the three domains are linked. Understanding the interaction between the three domains can help students make sense of the chemical and physical phenomena they are studying and experiencing. In chemistry, understanding chemical reactions requires the ability to link the three domains. A macroscopic experience of a chemical reaction can be understood using submicroscopic ideas, e.g., interaction of

particles. And these submicroscopic ideas are represented as symbols, e.g., chemical equation.

Drawing has been identified as valuable in science education because firstly, it enhances engagement in learning tasks and supports better science learning (Ainsworth et al., 2011). Drawing helps students learn the conventions of a particular representation, expresses conceptual understanding visually, and applies an effective learning strategy (Ainsworth et al., 2011). As a learning strategy, drawing supports a structured and systematic approach to learning (Fiorella & Mayer, 2015). In drawing to learn, a student may follow an organised sequence of cognitive processes. For example, in drawing to represent chemical reactions at the submicroscopic level, a student may follow a systematic, sequential, and iterative cycle of cognitive processes.

Secondly, drawing helps a student make his/her mental model visible and explicit (Ainsworth et al., 2011). Making the mental model visible and explicit for oneself helps the student see his/her understanding of the connections of ideas. For example, in representing chemical reactions at the submicroscopic level, drawing may help a student monitor the accuracy of his/her mental model. In the literature, there are several gaps in how students' submicroscopic drawings of chemical reactions were assessed. Students' drawings were assessed for their visual elements, i.e., the identity of the chemical species (e.g., magnesium atoms or magnesium ions) involved in the chemical reactions and conservation of particles (Davidowitz et al., 2010; Kern et al., 2010; Nyachwaya et al., 2011) but not for the spatial relationships between these visual elements (i.e., arrangement of particles and distance between particles). Spatial relations are examined in studies on students' understanding of states of matter but not chemical reactions. For the identity of the chemical species, previous studies predominantly evaluated students' drawings simply as involving particles that rearranged during chemical reaction (Chang et al. 2014; Davidowitz et al. 2010; Kern et al.

2010; Ryan and Stieff, 2019; and Yarroch, 1985). The interaction of electrons and formation of ions were not usually considered. In the few studies that have accounted for the formation of ions in students' drawings (Cheng, 2018; Cheng and Gilbert, 2017; and Nyachwaya et al., 2011), the features of the ionic species that can impact the complexity of the reactions were not considered.

Finally, drawing has been found to facilitate communication (Ainsworth et al., 2011). In making the mental model visible and explicit, the student can communicate his/her ideas to the teacher or peers. These 'knowledgeable others' (Vygotsky, 1978) can examine the expressed model and provide feedback to it (Ainsworth et al., 2011). This feedback from 'knowledgeable others' can be useful for the student to detect inadequacies in the mental model and carry out improvements. For example, generating drawings of chemical reactions can help students communicate their submicroscopic understanding. Then, receiving either teacher-feedback or peer-feedback can help the students check whether their submicroscopic understanding is scientific or not.

Feedback has been identified in existing research to play a powerful role in the development of students' self-regulation and learning (Butler & Winne, 1995; Hattie & Timperley, 2007; Hill & Edwards, 2019). In classroom teaching, teacher-feedback and peer-feedback are the common sources of external feedback encountered by students (Bedford & Legg, 2007; Cho & MacArthur, 2010; Coenders, 2016; Repice et al., 2016; Strijbos & Sluijsmans, 2010; Topping, 2010; Tsivitanidou et al., 2011). When teachers and/or students' peers provide comments or suggestions on students' learning artefacts, e.g., drawings, the feedback is contingent to the quality of drawing and the underlying mental model. The feedback can either affirm the accuracy of the drawing and the mental model or provide corrective directions if students misrepresented.

Teacher-feedback and peer-feedback exhibit distinct characteristics and affordances in supporting student learning. On the one hand, teacher-feedback is usually characterised as a one-way source of feedback (Tsivitanidou et al., 2011). The teacher who is usually regarded as the domain expert is the prime source of feedback. Hence, it is expected that teacher-feedback can provide accurate feedback ideas. It is one-way because the students as assesseees receive the feedback from the teacher without extended interactions between the two parties. Peer-feedback on the other hand, is usually characterised as a reciprocal source of feedback (Tsivitanidou et al., 2011) where students act both as assessors and assesseees for each other (Bedford & Legg, 2007; Cho & MacArthur, 2010; Repice et al., 2016; Tsivitanidou et al., 2011). It is reciprocal because exchange of ideas occurs among students as they take turns in giving and receiving feedback. As an assessor, a student can reflect on the quality of his/her own work as he/she examines and gives feedback on other's work. As an assessee, a student may benefit from receiving more feedback ideas from multiple peers.

The efficacy of teacher-feedback and peer-feedback has been largely studied in writing (e.g., Cho et al., 2008; Cho & MacArthur, 2010; Cho, Schunn, & Charney, 2006; Gielen et al., 2010a & 2010b; Paulus, 1999; Ruegg, 2015; Tajik et al., 2016; Yang et al., 2006; Yangin Eksi, 2012) but not in drawing to learn. Little is known about the features of feedback that can be valuable to support drawing to cultivate an understanding of the triplet relationship, particularly in large classes like the Philippines. Implementing teacher-feedback on drawing can be challenging because it requires extended effort and more time. I wanted to try to see if peer-feedback can be an alternative to teacher-feedback.

The ICAP (*Interactive, Constructive, Active and Passive*) theory (Chi, 2009, 2021; Chi & Wylie, 2014) describes a student's level of cognitive engagement during learning. According to this theory, there are four modes of students' overt behaviour when engaged in different learning activities: *Interactive, Constructive, Active and Passive*. Each mode of

overt behaviour is associated with supporting specific cognitive process and expected learning outcome. The *interactive* learning fosters the greatest cognitive engagement and hence highest level of student learning followed by *constructive*, *active*, and then *passive* learning (Chi & Wylie, 2014). Nevertheless, the ICAP theory has not been employed to describe cognitive engagement during feedback. The ICAP theory can be useful to describe how students engage with either teacher-feedback or peer-feedback. Consequently, this can contribute to an understanding of the conditions for effective feedback on drawing.

My research study aimed to investigate how teacher-feedback and peer-feedback influence students' freehand drawing of chemical reactions at the submicroscopic level. Drawing coupled with feedback as a teaching-learning strategy was used as a mediation tool to help students cultivate an understanding of the triplet relationship using chemical reactions as context. Learning outcomes in terms of recall and transfer one month after the intervention were assessed. Differences in the expected learning outcomes depending on the students' level of cognitive engagement (*interactive* vs. *active*) were compared. The level of assessment, i.e., higher (transfer) or lower (recall) level, is a factor that may impact the learning outcomes. Recall of information may not differ among different modes of learning based on the ICAP theory (Chi & Wylie, 2014). Hence, I also assessed transfer of student learning (i.e., their ability to apply the essential ideas about chemical reactions to a different but related situations). The next section presents the general and specific research questions that this study aimed to answer.

1.2 Research Questions

The general research question that this study sought to answer is: How may the two sources of feedback affect students' drawings of chemical reactions at the submicroscopic level?

Specifically, this study sought to answer the following research questions:

1. Is there a difference in the order of difficulty in drawing chemical reactions?
2. Is there a difference between the quality of students' drawings in the teacher-feedback group and peer-feedback group?
3. What are the features of feedback that are valuable for supporting drawing to learn chemical reactions?

1.3 Intervention and Measurement of Students' Learning: An Overview

The focus of this study was how feedback influenced students' drawings of their submicroscopic ideas of the types of chemical reactions. There were two experimental group conditions, namely, teacher-feedback group and peer-feedback group. The teacher-feedback group was regarded as *active* learning while peer-feedback was *interactive* learning (ICAP theory by Chi, 2009, 2021; Chi & Wylie, 2014). Student-participants in both groups performed practical work involving the four key types of chemical reactions that they studied in class, namely: combination/synthesis, decomposition, single displacement, and double displacement.

Participants of the research study included a chemistry teacher and two classes of Grade 11 Science, Technology, Engineering and Mathematics (STEM) students with 50 and 51 students in each class. These Grade 11 students were taking General Chemistry 1 during the first semester of the academic year 2018-2019 from a public laboratory high school in the Philippines. The intervention covered 12 lessons. Each lesson was 1-1.5 hours and there were two lessons per week. The first four lessons were practice lessons where students learned to draw the reaction on the extraction of iron and the dissociation of ethanoic acid in water. The eight remaining lessons were for the learning of the four types of chemical reactions and for data collection.

Worksheets were developed by the researcher to facilitate the conduct of the practical work, provide the working space for drawing and informing students of the feedback *foci* and *moves*. Students' drawings of their submicroscopic ideas of the four types of chemical reactions were assessed for their visual and spatial elements. These visual and spatial elements were scored using a rubric developed by the researcher. Number of feedback episodes and feedback *foci* and *moves* were recorded by videotaping the delivery of feedback during the whole-class presentation (teacher-feedback group) and in-group discussion (peer-feedback group). The transcripts of feedback episodes were analysed deductively and inductively. Students' learning outcomes, i.e., recall and transfer were assessed a month after the intervention (to account for incubation effects including students' rehearsal of knowledge in learning other related topics). Recall and transfer tests were composed of open-ended drawing test items developed by the researcher. Control variables, which include prior knowledge, spatial ability, and teaching conditions other than the intervention were considered.

1.4 Significance of the Study

This research study has potential theoretical and practical contributions. At the theoretical level, this study could fill in research gaps in the literature on drawing and feedback.

For drawing, existing studies usually assessed students' submicroscopic drawings of chemical reactions in terms of visual elements only, i.e., the identity of the chemical species involved in the chemical reactions and conservation of particles (Davidowitz et al., 2010; Kern et al., 2010; Nyachwaya et al., 2011). The researcher found only one study that assessed the spatial elements of students' submicroscopic drawings of chemical reactions. Ryan and Stieff (2019) analysed the spatial elements of students' submicroscopic drawings of chemical reactions as 'position' of particles according to its phase (i.e., solid, liquid or gas). Spatial

elements refer to the position or location of the represented chemical species (or parts of them) relative to the other chemical species. However, in the study of Ryan and Stieff (2019), ‘position’ was loosely used. It was not clear what exactly the word ‘position’ meant, i.e., arrangement of the particles or distance between particles. Also, in assessing drawings of the identity of the chemical species involved in the chemical reaction, the particle model was predominantly used (i.e., chemical reactions simply involved spatial rearrangement). Although there are few studies that applied the atomic model to describe chemical reactions (i.e., interaction of electrons and formation of ions), the features of the ionic species involved and its impact on the complexity of the reactions were not explored. My study addressed these gaps on drawing by assessing both visual and spatial elements of students’ submicroscopic drawings of chemical reactions. For visual elements, both the particle and atomic models were used to describe the identity of the chemical species involved. More so, spatial elements in my study include both arrangement of particles and distance between particles.

For feedback, previous studies on the efficacy of teacher-feedback and peer-feedback were largely conducted in the context of writing to learn but not in drawing to learn. Studies on the features and conditions of the two feedback sources that are valuable in supporting drawing particularly for large classes (where teacher-feedback is challenging to implement) are lacking. Also, the ICAP theory has not been applied to student engagement during feedback. The ICAP theory (Chi & Wylie, 2014) suggests that an *interactive* mode of engagement is more likely to lead to better learning outcomes than the other modes of engagement. The ICAP theory identifies two criteria for students’ dialogues to be considered *interactive* and beneficial to learning, namely: (a) dialogues are at the *constructive* mode and (b) that there is a sufficient degree of turn-taking. However, the ICAP theory has not demonstrated how students’ level of conceptual knowledge impact learning outcomes. If

students have developing level of conceptual knowledge, will the expected learning outcome of the *interactive* mode still hold? The current study addressed these gaps on the feedback literature by comparing learning outcomes of Filipino students who received either teacher-feedback (expert feedback with *active* student engagement) or peer-feedback (novice feedback but involving *interactive* student engagement) in drawing reactions. The *foci* and *moves* used by both teacher-feedback and peer-feedback provides insights into and behind conditions for their effectiveness.

At the practical level, this research work could potentially contribute to linking theoretical ideas about the effectiveness of drawing and feedback as a teaching-learning strategy to its actual implementation in the classroom (praxis). The insights on the complexity of drawing reactions and features of feedback valuable for supporting drawing to learn reactions can inform chemistry teachers on how they can potentially adapt the teaching-learning strategy particularly for large classes to cultivate an understanding of the triplet relationship.

Chapter 2 Literature Review

This chapter presents a review of previous studies on both drawing and feedback in the context of thinking and learning. This literature review is divided into two major sections – beginning with drawing and then on feedback.

2.1 Drawing

This section covers the literature review for drawing. The section begins by describing what is drawing. In particular, reference is made to representing submicroscopic entities. This study involved students in drawing. The affordances and limitations of freehand drawing of chemical reactions at the submicroscopic level are presented to demonstrate its appropriateness as a teaching-learning strategy. Drawing is a cognitive as much as it is a motor task. This study focused on drawing to learn and was less on developing the motor/technical skill of drawing. The cognitive processes involved when drawing chemical reactions of different complexity and while receiving feedback are discussed. I am aware that spatial ability may impact students' ability to draw. The discussion on the cognitive processes extends to spatial ability as an important factor to consider when studying student drawing.

Drawings as artefacts of students' submicroscopic understanding of chemical reactions have affordances and limitations. It is critical to recognise these affordances and limitations to accurately assess the quality of drawing. Existing studies are examined for the different ways that drawings of chemical reactions were assessed. I have identified that chemical reactions are typically assessed as spatial rearrangement of particles. The interaction of electrons and the formation of ions are not usually considered. Features of the ionic species involved in the reaction may influence how well the students can draw the reaction. Furthermore, in assessing students' drawings of chemical reactions, spatial relationships among visual elements of the drawings (e.g., arrangement and distance between particles) were vaguely characterised or usually ignored. Hence, I propose a visual-spatial assessment

framework to address these gaps. Selected students' drawings were used to illustrate the potential of the visual-spatial assessment framework. Towards the end of this section, I suggest that the proposed visual-spatial assessment framework could advance how students' drawings of chemical reactions at the submicroscopic level are evaluated.

2.1.1 What is Drawing as a Teaching-Learning Strategy?

Drawing is described as a human activity that involves the purposeful creation of a visual representation of a particular object, concept, situation, or phenomenon. The representation can be reinterpreted for thinking, learning, and communicating (Forbus and Ainsworth, 2017). For thinking and learning, drawing involves making visually explicit the relationship among initially implicit elements. This process of making explicit the relationship among implicit elements leads to the creation of new insights. To communicate, drawing involves the creation of a visual artefact that can be examined, analysed, discussed, and annotated by others to generate ideas and communicate them (Forbus & Ainsworth, 2017). As an artefact for classroom teaching and learning, the teacher can provide feedback on drawings so that students can refine not only the drawing but the ideas that underly the drawing. Hence, it is not just learning to draw, but drawing to learn (Kantrowitz et al., 2017). As a learning tool, drawing in this study focused on functional concerns (i.e., purpose and process) rather than aesthetic concerns (i.e., whether the drawing looks good or bad) (Kantrowitz et al., 2017).

Drawing as a representational tool can be used in two ways. Firstly, drawing can be used to accurately share, depict, or replicate the physical resemblance of a referent (object, concept, situation, or phenomenon) via traditional means like paper and pen (freehand). In other words, drawing can be used to generate a visually and spatially isomorphic representation of the referent. A visually and spatially isomorphic representation means that the structural and spatial relationship of the elements in the drawing looks exactly like the

referent (Cheng & Gilbert, 2015). Secondly, drawing can be used to describe important elements of the referent but not to replicate its physical appearance. Representations like matrix notes, flowcharts, diagrams, and computer-aided representations translate the physical image of a referent into conventions prescribed by the representation (Van Meter & Garner, 2005). Diagrams used to represent submicroscopic entities may not be visual and spatial isomorphic depictions of their referents. But these submicroscopic diagrams are used to share, depict, and replicate an accurate structural and spatial resemblance of those referents not accessible to direct human experience (e.g., submicroscopic entities like subatomic particles, atoms, molecules, and ions).

This study describes drawing as a teaching-learning strategy that involves the production of a visual artefact of students' submicroscopic understanding of chemical reactions. Existing studies have identified the usefulness of drawing as a teaching-learning strategy in science education. Three major benefits of drawing as a teaching-learning strategy have been identified.

Drawing Enhances Engagement. Firstly, drawing has been found to enhance engagement in the learning task (Ainsworth et al., 2011) especially if used with support. Mohler and Miller (2008) conducted a study about the usefulness of mentored sketching for enhancing the sketching and spatial skills of undergraduate engineering students in the US. Freehand sketching assignments and computer-aided design demonstrations were done by both instructors and students. The instructors conducted a mass demonstration of the proper sketching techniques while students practised doing it. Then, students submitted their freehand sketches with annotations at the end of each lecture. The mentored sketching helped students to see in real-time how to draw engineering graphics concepts. As a teaching strategy, mentored sketching helped improved students' engagement during their computer graphics class. And it encouraged students' attendance and sustained students' interest during

lectures. The instructor and students also had opportunity for greater interaction through mentored sketching.

Drawing Facilitates Learning. Secondly, drawing supports better science learning. Several studies that affirm this usefulness of drawing in supporting better science learning were conducted among high school students in Germany in the context of reading science text. For example, Grade 7 students who drew freehand during the reading of science text and implemented the strategy with high quality drawings had better recall compared to students who self-explained (Scheiter et al., 2017). Grade 10 students who used drawing instruction when learning a science text had better visualisation, transfer, and comprehension than those who made use of text-based instruction (Leopold & Leutner, 2011; Leopold et al., 2013). Drawing accuracy and post-test performance were found to be positively correlated. Also, drawing can mediate between text comprehension and post-test performance (Van Meter & Garner, 2005).

In geology, a study conducted among undergraduate students in the USA compared three teaching strategies: (1) Drawing diagrams including prediction of the spatial relations that are not directly observable, (2) copying diagrams without predicting the spatial relations, and (3) making predictions without drawing. It was found that drawing diagrams while predicting spatial relations supported a better understanding of the 3D relations in geologic block diagrams. This effect of drawing in supporting a better understanding of 3D relations is regardless of the number of drawings produced (Gagnier et al., 2017). Additionally, students who drew the spatial relations accurately demonstrated greater improvement in their understanding of 3D diagrams compared to those who had inaccurate drawings. This greater improvement in understanding of 3D diagrams among students who accurately drew the spatial relations might be because drawing prediction supported them in linking their spatial inferences about the geologic block diagrams to their constructed diagrams. Students

considered what should be in their drawings and how they should be represented. The drawings served as visible and explicit artefacts that were used by the students to assess the accuracy of their mental models and compare it with the correct one or with others to promote learning. Yet to support better learning through drawing, the study recognised the need to come up with instruction (e.g., spatial feedback) to help students assess their drawings against an exemplar (Gagnier et al., 2017).

In chemistry, studies about drawing supporting better learning were conducted in General Chemistry courses. In an Australian university, first-year undergraduate students recognised that using physical models and drawing to support explanations during lectures supported their learning on the topics of Valence Shell Electron Pair Repulsion (VSEPR) and Hybridization (Ferreira & Lawrie, 2019). On cultivating submicroscopic understanding via an online environment, US students who were exposed to a drawing curriculum have benefited from it. Here I review three studies:

- i. Undergraduate students who completed the *CLUE (Chemistry, Life, the Universe, and Everything) curriculum* were asked to construct drawings of atomic-molecular representations. Then, the students were asked to explain how these submicroscopic structures determine the properties and behaviour of chemical phenomena. Results showed that the students who completed the *CLUE curriculum* were at least one or sometimes two semesters ahead of the control group. The students were better at drawing molecular structures and at indicating that structure can determine physical and chemical properties (Underwood et al., 2016).
- ii. University students demonstrated better submicroscopic understanding because of the incorporation of drawing activities during simulation of molecular behaviour on the topics of particulate nature of matter, solvation, acidity, kinetic molecular theory, chemical reactivity, and equilibrium. The drawing activities were adapted from the

CCC (*Connected Chemistry Curriculum*). The improvement in the submicroscopic understanding is independent of the two components of representational competence (Hadenfeldt et al.): (1) Novel generation of representations and (2) consistent selection of representations. The novel generation of representations is the ability to invent new representational features for the drawing. These new representational features were not originally introduced in the drawing task. The selection of representations is the ability to choose a representation that best communicates the target conceptual idea. Conversely, the quality of submicroscopic understanding was dependent on the quality of the drawings. Producing drawings with more accurate conceptual features were positively associated with submicroscopic understanding. Generating drawings with features that accurately apprehend the conceptual ideas (conceptually high-fidelity drawings), predicted better submicroscopic understanding. Nevertheless, the study identified the need for scaffolds to aid the construction of drawings that demonstrate high conceptual fidelity (Stieff & DeSutter, 2021).

- iii. Secondary students who completed the CCC that combined drawing with dynamic visualisation of molecular phenomena performed significantly better on achievement tests as compared to those who did not use the curriculum. Students who completed more drawings showed the greatest learning. These students who completed more drawings were most likely to include accurate drawings in their summative assessments. The students used these drawings to support their explanations of submicroscopic phenomena. Drawing supported students to develop more accurate mental models of the behaviour of molecules (Cooper et al., 2017).

Drawing is beneficial to science learning because conceptual understanding in science is based on reasoning with multiple and often visual modes of communication (Ainsworth et

al., 2011). Drawing supports reasoning and learning of content in which visual and spatial information are essential (Forbus & Ainsworth, 2017). Also, most conceptual difficulties in science are representational (Prain & Tytler, 2012), meaning that students struggle with discerning the relevant features of a representation that can help them make sense of the represented scientific phenomenon. Drawing as a teaching-learning strategy facilitates reasoning in science by helping learners focus on relevant features of each of these modes of representation (Ainsworth et al., 2011). Drawing as a visual representation can invoke a student to make the connections between implicit and vague relevant features of each mode of representation (e.g., the chemical equation of a chemical reaction and the submicroscopic diagrams of the same chemical reaction) to become visually explicit leading to the creation of new insights (e.g., quantitative relationship in the chemical equation and its connection with the conservation of particles as a visual element of the submicroscopic diagram) (Forbus & Ainsworth, 2017). Drawing helps make conceptual difficulties visible by helping students mentally simulate a process, refine and disambiguate mental images, reorder information, and direct one's attention to unsolved parts of the problem (Johnson & Reynolds, 2005).

Higher-order, not lower-level, assessments are sensitive to the effects of drawing (Van Meter & Garner, 2005). Tests that measure recall of factual knowledge showed unfavourable results compared to the development of mental representations, establishing relationships, problem-solving, application, and higher-level comprehension. This sensitivity of drawing to higher-order assessments is because during mental model construction, a student makes connections between ideas rather than just recalling isolated facts (Van Meter & Garner, 2005).

Drawing Fosters Communication. Thirdly, drawing facilitates communication. When students draw, they produce a shared visual artefact of their ideas. This shared artefact can be used by both the students and others (i.e., teacher or peers) to examine, discuss and

refine those underlying ideas. The drawing serves as a way for a student to grant others access into their thinking (Ainsworth et al., 2011). For example, in the context of geology education, undergraduate and graduate students of geoscience in the US drew photographs of rock formations and causal diagrams. It was found that the students made use of their domain-specific spatial and conceptual knowledge rather than a general form of knowledge like spatial thinking or visualisation to produce those drawings (Jee et al., 2014). By making that domain-specific spatial and conceptual knowledge explicit through drawing, the students can begin communicating them to others. Through drawing, students could reveal their knowledge gaps, alternative conceptions and misconceptions as influenced by prior learning experiences to others so that they can respond and provide feedback (Copeland Solas & Wilson, 2017).

When students begin communicating their ideas via drawing, the provision of external support in the form of feedback from ‘knowledgeable others’ (student’s peers or the teacher) (Vygotsky, 1978) can be used to check the accuracy of the drawing and the underpinning mental model. Through this provision of external support, inadequacies could be detected and corrected. Without such external support, those inadequacies might go unnoticed. Feedback from either the teacher or students’ peers can serve as scaffolds to productively constrain students’ attention to the important aspects of the to-be-learned material. Students who receive external support during drawing can engage in communication and at the same time self-monitor their conceptual understanding. Further, as the level of students’ prior knowledge increases, the external support that is needed decreases (Van Meter & Garner, 2005).

Drawing, because of its benefits in learning, has been used together with other teaching-learning strategies, e.g., use of computer software (Forbus et al., 2011; Garnier et al., 2017; Underwood et al., 2016), dynamic visualisation of molecular phenomena (Cooper

et al., 2017), physical models (Ferreira & Lawrie, 2019), and classroom demonstration (Mohler & Miller, 2008). Drawing has also been implemented in different learning contexts, e.g., engaging in lectures (Ferreira & Lawrie, 2019; Mohler & Miller, 2008), reading comprehension of science texts (Leopold & Leutner, 2011; Leopold et al., 2013; Scheiter et al., 2017), watching animations (Lowe & Mason, 2017; Ploetzner & Fillisch, 2017), and learning of 3D diagrams (Gagnier et al., 2017). Additionally, drawing has been used in the context of cultivating submicroscopic understanding (Cooper et al., 2017; Stieff & DeSutter, 2021; Underwood et al., 2016). Particulate drawings are utilised to represent students' submicroscopic understanding of chemical reactions and are used together with pictures (Cheng, 2018; Cheng & Gilbert, 2017) and chemical equations (Nyachwaya et al., 2011). I did not find studies that paired drawing with feedback as a strategy in learning chemical reactions from practical work.

In sum, drawing is useful as a teaching-learning strategy because it: (1) Enhances engagement in the learning tasks. And (2) drawing supports better learning for science in general and chemistry in particular. Cooper et al. (2017) identified that more drawing activities are associated with better submicroscopic understanding. Other studies, however, have pointed out that it is the accuracy of the conceptual ideas in the drawing that is associated with better learning from drawing (Gagnier et al., 2017; Scheiter et al., 2017) particularly better submicroscopic understanding (Stieff & DeSutter, 2021). (3) Drawing facilitates communication (Ainsworth et al., 2011). When students begin communicating their ideas through drawing, external support in the form of scaffolds with features that support students to construct drawings that could promote better conceptual understanding is needed (Gagnier et al., 2017; Stieff & DeSutter, 2021). What is known though, is that feedback from teachers or students' peers as 'knowledgeable others' (Vygotsky, 1978) has a critical role in the efficacy of drawing as a teaching-learning strategy. It is worthwhile to

investigate what specific features of feedback (e.g., feedback on visual-spatial elements of the drawing, verbal linkages with the drawing, triplet relationship and prerequisite chemistry knowledge) from students' peers and teachers could promote accurate drawings and in effect, support better submicroscopic understanding. The next section presents the affordances and limitations of freehand drawing of submicroscopic phenomena.

2.1.2 Why Freehand Drawing?

The previous section reviewed the benefits of drawing as a teaching-learning strategy. Given the widespread use of multimedia technology, there are studies that examined the use of computer drawing tool to support learning. In this study, I chose to utilise freehand drawing because it is more viable and economical to implement for large classes compared to computer drawing. The following are the affordances of freehand drawing compared to computer drawing when representing students' submicroscopic ideas of chemical reactions:

1. Freehand drawing can provide a more flexible drawing space compared to computer drawing. Depending on the student, he/she could easily maximise the drawing space on a blank sheet of paper. The student is also free to decide the size of his/her drawing space, depending on the chosen size of the paper. This is unlike computer drawing where usually a given drawing space (size of canvas) has a definite number of pixels that determine the quality of drawing details (resolution). This resolution is usually predefined by the software, and by the quality and size of the device being used. The size of the drawing space is important because it determines the extent of the drawing and hence the range of submicroscopic ideas that the student can represent within that drawing space.
2. Freehand drawing takes fewer steps than computer drawing to implement. A student can easily draw, modify, and add annotations or labels depending on his/her strategy. These fewer steps associated with freehand drawing makes it more efficient at

representing submicroscopic ideas; compared to computer drawing where a student needs to do additional steps like searching for a command, opening a dialogue box, clicking a tab or button, or dragging the cursor before the desired actions can be executed. During these additional steps, pieces of separate information are presented at different areas of the screen frame and at different times. These spatially and temporally distant pieces of information should be processed mentally to complete the drawing task. This processing of spatially and temporally distant pieces of information escalates extraneous cognitive load and contributes to split attention effects (Schroeder & Cenkci, 2018).

3. On the one hand, freehand drawing as a cognitive task increases germane cognitive load (the type of cognitive load that refers to inferential processes used to understand a learning content) by invoking the student to reflect on their understanding of the submicroscopic phenomenon and how to represent it. This increased germane cognitive load is beneficial because it contributes to a better understanding of the learning content (Schleinschok et al., 2017). On the other hand, computer drawing is likely to add to extraneous cognitive load. During computer drawing aside from reflecting on their understanding of the submicroscopic phenomenon and how to represent it, the student needs to think about his/her knowledge of the software and how to apply it. More so, depending on how extensive the student's knowledge of the software, it can limit how he/she can use the software to represent his/her submicroscopic ideas.
4. In the freehand drawing, a student has a freer choice of conventions and symbols that best represent his/her submicroscopic ideas. This is unlike computer drawing where conventions and symbols are usually pre-set by the software being used. The student is bound to represent his/her ideas based on what is only offered by the software.

Hence, freehand drawing could provide a more authentic account of the student's submicroscopic ideas. Note, however, that the conventions and symbols should be those that accurately apprehend the conceptual ideas because producing them contributes to better conceptual learning (Stieff & DeSutter, 2021).

5. Freehand drawing is more cost-effective to implement than computer drawing.

Drawing tools are readily and inexpensively available compared to purchasing expensive drawing software and electronic devices like tablets or computers. More so, freehand drawing can easily be implemented in the classroom, unlike computer drawing where additional preparation and resources are needed in training teachers and students on how to use a particular drawing software and electronic device.

Yet, freehand drawing as a representational tool for students' submicroscopic ideas poses the following limitations:

1. Freehand drawing cannot directly show dynamic visualisation of chemical species especially the ways that objects relate to each other (in space within a given time sequence) compared to computer drawing software. For example, for freehand drawing during a chemical reaction where atoms interact, and electrons are either transferred or shared, arrows or annotated marks can be used to denote the spatial interaction or movement. A series of separate static drawing frames can be used to show temporal changes. This is unlike when using computer drawing where such spatial interaction or movement, and temporal changes can directly be shown at once.
2. Freehand drawing reduces a 3D phenomenon into a 2D representation. Reducing 3D phenomenon into a 2D representation requires additional spatial skills (translation, representation, orientation, or form perception among others) for the students and teachers to create a coherent understanding of the concepts being represented. The student might require technical drawing skills like perspective, contrast, and shading

techniques to depict 3D effects. This is compared to some computer drawing platforms that use dynamic visualisation so that 3D phenomenon can readily be represented as 3D phenomenon per se; nonetheless, 3D drawing remains a challenge even via computer drawing.

3. Freehand drawing has been found not to support learning from animations, especially those animations that are complex and are not accompanied by a spoken or written text (Lowe & Mason, 2017; Ploetzner & Fillisch, 2017). Freehand drawing does not support learning from animations because (a) such kinds of animation do not involve text where a verbal model is being transformed into a pictorial representation; (b) 3D dynamic visualisation is reduced to static representation where visuospatial (how objects relate to each other and are perceived in a given space) details are more focused on rather than spatiotemporal details; and (c) the student may lack the necessary drawing skills to represent the essential visuospatial and spatiotemporal details of the complex animation (Lowe & Mason, 2017).

Based on the previous review of the affordances and limitations, freehand drawing was deemed useful for my research. Drawing chemical reactions at the submicroscopic level is a cognitively demanding task. Students need to know, integrate, and apply a range of prerequisite and interconnected chemistry concepts. These chemistry concepts could include: Distinguishing atoms, molecules, and ions; identifying polyatomic ions; assigning charges of ions; recognising chemical symbols; naming and writing chemical formulae; distinguishing ionic, covalent, and metallic bonding; applying the Law of Conservation of Mass; and recognising particle arrangement of the three states of matter, among others. Additionally, in the Philippines, chemistry classes are usually large (50 students or more) (Class Size and Conditions Act, 2022) and freehand drawing tools are readily and inexpensively available

compared to expensive drawing software and electronic devices like tablets or computers. Freehand drawing is recognised to provide an ecologically valid and cost-effective teaching-learning strategy associated with a less extraneous but more germane cognitive load. The next section presents the cognitive processes that may be involved when drawing chemical reactions of different complexity while receiving feedback.

2.1.3 What Cognitive Processes are Involved in Drawing to Learn Chemical Reactions of Different Complexity?

I would use the literature on the cognitive processes involved when drawing to learn from science texts and from animations to deduce the cognitive processes involved in drawing chemical reactions of different complexity. In drawing to learn from science texts, three cognitive processes are involved – selection, organisation, and integration. These three cognitive processes are based on the Generative Theory of Drawing Construction (Van Meter & Garner, 2005). During selection, a student is presented with an external verbal representation, i.e., written text to be read. The student selects the essential and non-essential elements of the written text. The selected essential elements are organised into a coherent internal verbal representation that will guide the construction of an internal visual representation. During the construction of the internal verbal and visual representations, the student tries to make connections between the selected essential elements; this is the organisation process. It is noteworthy that the organisation process is not linear and prior knowledge has a critical role as support. The student creates the internal verbal and visual representations that are based on his/her prior knowledge. At the integration phase, the internal verbal representation is connected to the internal visual representation to create a mental model (Van Meter & Garner, 2005). Mental models are “internalized, organized knowledge structures that are used to solve problems. Mental models are created with respect to the spatial, temporal, and causal relationships of a concept” (Rapp, 2005, p. 46). In other

words, a mental model is a visual representation of the science text. The mental model serves as the basis for making inferences, which students can use to gain a deeper understanding of the science text (Leopold & Leutner, 2011).

In drawing to learn from animations, students are processing a pictorial representation (animation) that involves dynamic temporal changes rather than a written text. This pictorial representation (animation) is then transcribed into a drawing, which is still a pictorial representation (Ploetzner & Fillisch, 2017). The Animation Processing Model (Lowe & Boucheix, 2008) suggests five cognitive phases that might occur in learning through animations.

- i. Localised perceptual exploration (Phase 1) involves segmenting the animation's continuous influx of dynamic information into local discrete event units.
- ii. Regional structure formation (Phase 2) involves the formation of relationships (e.g., causal links) between the discrete event units from Phase 1. The discrete event units are condensed into regional structures, which are isolated chunks of the relationship between the local discrete event units.
- iii. Global characterisation (Phase 3) involves connecting the isolated chunks of regional structures to create a mental representation of how the overall system works across space and time. In other words, the chunks of regional structures are arranged into sequence to show how the actions depicted in the animation flow. During Phase 3, prior knowledge is crucial. The lack of prior knowledge can impede the process of creating the mental representation because the subtle but important aspects of the animation can be overlooked.
- iv. Functional differentiation (Phase 4) involves understanding how the sequence of actions identified in Phase 3 contributes to the functionality of the overall system

depicted in the animation. Phase 4 includes understanding how each subsystem works and contributes to the functionality of the overall system.

- v. Mental model consolidation (Phase 5) involves the development of a flexible mental model. Such mental model that can be used to explain the depicted system under different conditions (Lowe & Boucheix, 2008, 2011).

In both learning contexts, i.e., drawing to learn from science text and from animations, the cognitive processes involved are sequential and iterative: Initially, the student encounters pieces of information and selects the essentials and non-essentials. Then, he/she tries to build connections among these pieces of information. Building connections lead to the creation of a mental model, which is a visual representation of the to-be-learned material. While building connections, the student may review the selection process to ensure the quality of the mental model created. It is my view that these sequential and iterative cognitive processes can serve as a guide to conceptualise how a student learns when drawing chemical reactions at the submicroscopic level based on macroscopic observations.

In drawing a chemical reaction based on a macroscopic phenomenon, the student would first infer what is happening at the submicroscopic level that could describe what he/she is perceiving. These inferences might include: surmising the products formed by the chemical reaction based on the observed macroscopic changes (e.g., magnesium ribbon burning with a bright white flame indicating the formation of magnesium oxide and glowing wooden splint above a solution indicating the release of oxygen); describing the phases of the reactants and products; recognising changes in submicroscopic particles in the chemical reaction; and identifying the quantitative relationship between the reactants and products. The chemical equation of the chemical reaction as a symbolic representation can guide the student in generating his/her inferences. The student can refer to the chemical equation for the identities

of the reactants and products based on their chemical formulae (atoms, molecules, and ions); phases of the reactants and products based on the state symbols (s, l, aq or g); and the amount of the reactants and products based on the ratio (coefficients) in the balanced chemical equation.

After making pieces of separate inference, the student organises them by building connections among them. The process of building connections can send the student back to examine the generated pieces of inference. If meaningful connections cannot be made, students may step back to check for any missing or flawed inference. Prior knowledge plays a vital role in both generating inferences and organising them. If the student has a high level of prior knowledge, he/she can detect conceptually relevant inferences and connections. If he/she has a low level of prior knowledge, he/she can likely detect only surface level inferences and connections (Cook, 2006; Cook et al., 2008; Corradi et al., 2014). Additionally, reciprocal relationships exist among macroscopic observations, chemical equation and generating inference. The chemical equation serves as a guide to making inferences about the macroscopic observations. Reciprocally, generated inferences are used to interpret both chemical equation and the macroscopic observations. Prior knowledge can influence the quality of inferences and their connections and affect the interpretation of both the chemical equation and macroscopic observations.

The organised inferences are encoded to form internal verbal and visual representations, which are then integrated to create a mental model. This mental model is a visual representation of the student's submicroscopic explanation of the chemical reaction. This mental model is externalised as a drawing. When students recognise changes in submicroscopic particles, non-transformation of particles (atoms remain as atoms; molecular species remain molecular) during chemical reactions is less challenging than recognising particle transformation (atoms or molecules to ions or vice versa). When drawing a chemical

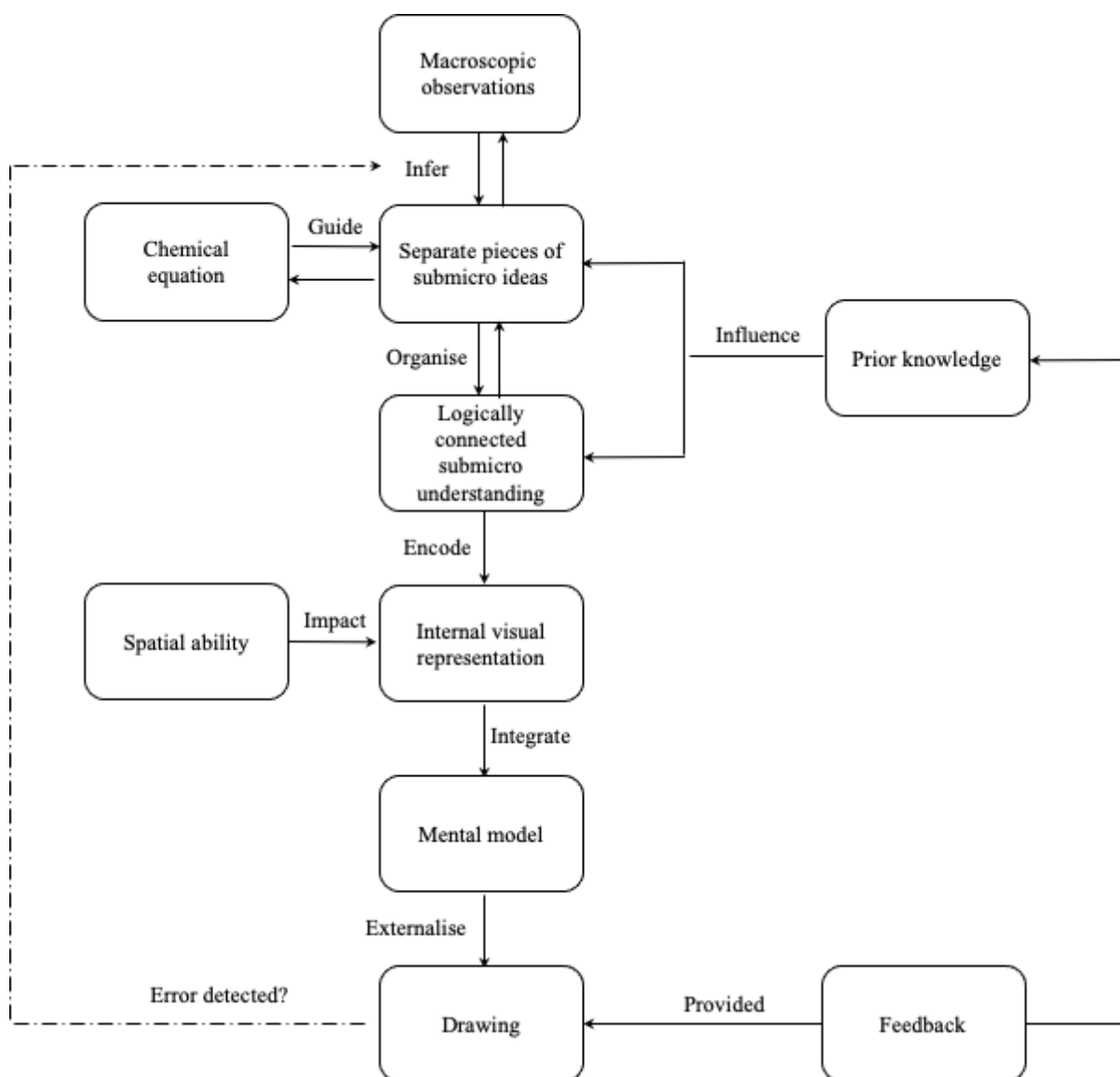
reaction that does not involve particle transformation, the student would need to use prior knowledge on concepts like the difference between atoms and molecules, Law of Conservation of Mass, and particle arrangement and distance based on phases. When drawing a chemical reaction that involves particle transformation, students would also need to know additional concepts like how ions are formed (electron transfer), how ions are distinguished from atoms and molecules, the identity of polyatomic ions, assignment of charges and formula writing.

During the externalisation of the mental model as a drawing, the quality of the generated inferences and the relationship between them become more explicit. The student's peers and teacher can examine the relationship among these inferences and provide feedback. If the feedback detects any errors, the student can move back to check the quality of generated inferences and repeat the process of generating and organising these inferences. Feedback information can also add to existing student prior knowledge. This prior knowledge impacts both the quality of submicroscopic inferences and their connections, which are then utilised to interpret both chemical equation and the macroscopic observations. Hence, feedback, by extension, influences a student's understanding of both the chemical equation and the macroscopic phenomenon.

It is my view that these cognitive processes during drawing of chemical reactions, i.e., from making submicroscopic inferences about the macroscopic phenomenon to receiving feedback onto the drawing is iterative. Drawing to learn can be viewed from a constructivist perspective, which describes learning as incremental (making separate pieces of inference and organising them), interpretive (students use their prior knowledge to generate submicroscopic inferences about the practical work using chemical equation as a guide and build connections among the generated inferences) and iterative (the cognitive processes are

sequential and recurring) (Taber, 2014). A flowchart of these processes is presented in Figure 1.

Figure 1 Flowchart of the Cognitive Processes Involved When Drawing to Learn Chemical Reactions of Different Complexity While Receiving Feedback



In sum, as a teaching-learning strategy, drawing involves the process of transforming visible information (i.e., written text, dynamic animation, macroscopic observations, or chemical equations/formulae) into a mental model. Drawing as a teaching-learning strategy

involves making organised inferences about the visible information and representing them as a visual artefact (Gagnier et al., 2017). These iterative cognitive processes demonstrate that drawing can support a structured and systematic approach to learning (Fiorella & Mayer, 2015). The organised sequence of the cognitive processes provides a structure that students apply when drawing to learn. Drawing can also induce cognitive and metacognitive processes (Ploetzner & Fillisch, 2017) as seen from the capability of students to self-monitor the accuracy of their mental models especially with external support from others. Hence, students' drawings can be used as artefacts of their thinking and learning.

Drawing as a teaching-learning strategy has limitations. Drawing does not always mirror conceptions that students hold. The study of Ehrlén (2009) found that Swedish children (6 to 9 years old) drew the Earth using conventional representations. However, when interviewed, the children presented conceptions inconsistent with their drawings. The children drew based on the existing conventions yet held alternative conceptions. Hence, it is a possibility that conventional drawings might not always precisely represent the student's conceptions. Certain aspects of students' understanding might have been left unnoticed when drawing is used in isolation. Drawing does not give a complete picture of the students' understanding. To address this limitation in the research study of Ehrlén (2009), drawing needs to be coupled with other modalities including symbolic representations and written annotations (Ryan & Stieff, 2019). These other modalities can help discern how students attempt to process information presented to them (Davidowitz et al., 2010). The annotations may include labels or legends of the chemical species involved in the chemical reaction to indicate their identities, and a written description or explanation of the submicroscopic events. Additionally, drawing as a cognitive endeavour is impacted by other cognitive process like spatial ability. The subsequent section discusses how spatial ability impacts the drawing of chemical reactions at the submicroscopic level.

2.1.4 How is Spatial Ability Related to Drawing of Chemical Reactions at the Submicroscopic Level?

Spatial ability is described as the ability to construct, represent, manipulate, transform and/or interpret spatial information of mental images to perform cognitive tasks (Hegarty & Waller, 2005; Poltrock & Brown, 1984). Spatial visualisation is a fundamental dimension of spatial ability, which is described as the ability to mentally manipulate, rotate, turn, twist, or invert an object or parts of it represented pictorially (Guilford & Lacey, 1947; Michael et al., 1957). Spatial visualisation has been identified as most useful in solving difficult spatial problems (Carroll, 1993). When asked to draw a chemical reaction at the submicroscopic level, a student would need to imagine how the arrangement and distance between particles of the chemical species changed before and after the chemical reaction. For example, when drawing the chemical reaction between magnesium and oxygen producing magnesium oxide, the student visualises how the arrangement of the particles of solid magnesium metal and diatomic oxygen gas rearranged to form a solid magnesium oxide crystal. Doing so, the student mentally moves part(s) of the images of the particles relative to other parts or other entities in the drawing. It is surmised that spatial ability impacts the cognitive process of drawing during the creation of an internal visual representation (see Figure 1).

The Paper-Folding Test VZ-2 is a test that has been used to assess spatial visualisation (Carroll, 1993; Lohman, 1988; McGee, 1979; Michael et al., 1957). It is a test that assesses visuospatial transformation of mental imagery or the “ability of a person to apprehend, encode and mentally manipulate abstract spatial form” (Williamson et al., 2017, p. 14). Hence, this test can be used to isolate the effects of spatial ability on drawing during quantitative analysis. Freehand drawings as artefacts of students’ submicroscopic understanding of chemical reactions present certain benefits and limitations. These benefits and limitations are presented in the next section.

2.1.5 What are the Affordances and Limitation of Freehand Drawings as Artefacts of Submicroscopic Understanding of Chemical Reactions?

In the broader context of science education, I reviewed three studies that examined the affordances and limitation of freehand drawing as representation of student thinking and learning.

- i. On learning physical science concepts like circuits, magnets, electromagnetism and lightning, Year 7 students in the USA were asked to either summarise or draw their understanding of the reading passages about the concepts. Using the summary or the drawing as an aid, students answered post-test questions. The results showed that spatial relations, e.g., arrangement and completeness of an electric circuit are vaguely represented in the summaries but are well represented in the drawings (Kunze & Cromley, 2021).
- ii. For chemistry, a study among university and secondary teachers and students in the USA was conducted on the topics of physical and chemical equilibria. In the study, the participants generated macroscopic and submicroscopic written explanations and drawings of their conceptual understanding of liquid–vapour and dissolving–recrystallization (solubility) equilibria (physical equilibria) and dimerization reaction of nitrogen dioxide (chemical equilibrium). The results showed that at the macroscopic level, written responses focused more on features of motion and processes while drawings were about the physical and observable structures. At the submicroscopic level, written responses were about the dynamic processes involved in the equilibria while drawings were about physical or macroscopic structures as well as particulate structures (Akaygun & Jones, 2014).
- iii. For a topic on visualising and learning a new organic reaction mechanism, university students in Canada were interviewed after they drew the mechanistic arrows,

products, and transition state structure of the epoxide-opening reaction mechanism.

The results showed that students used two mental models: Static (use of symbols and structures without dynamic meanings like electron transfers, reaction process, or particle dynamics) and dynamic (reactivity as a process of electron transfer, and/or as particles in motion during bond breaking and forming). More so, the students struggled in showing the dynamic mental model in their drawings (Bongers et al., 2019).

These three studies demonstrate that freehand drawing has been found useful in representing static structures (macroscopic or particulate) and the spatial relationships between these static structures (e.g., arrangement of the components, i.e., switch, battery and bulb in an electric circuit; position of physical structures, i.e., flask, beaker, solid or solution in the drawing; arrangement of molecules and distance between them) (Akaygun & Jones, 2014; Bongers et al., 2019; Kunze & Cromley, 2021). Features of motion and dynamic processes, e.g., electron transfer, are rarely represented by students during freehand drawing (Bongers et al., 2019). Electron transfer implicates changes in the identity of the particles (atoms or molecules to ions, or vice versa). It is my view however, that such changes at the particle level, which is an important dynamic process can be represented via freehand drawing. Changes in the visual details (e.g., discrete circles, connected circles, colours, shades and annotations) of the drawing can be used to show such changes in the identity of the particles. Table 1 summarises the affordances and limitation of freehand drawings as demonstrated in the three studies discussed.

Table 1 *Affordances and Limitation of Freehand Drawing as Artefacts of Submicroscopic Understanding of Chemical Reactions*

	Affordances	Limitation
Freehand drawing	Can represent static structures and their spatial relationships	Rarely can represent dynamic processes

The subsequent section describes how drawings of students' submicroscopic understanding of chemical reactions have been assessed in the literature. It has been identified that previous studies usually assessed drawing chemical reactions simply as spatial rearrangement. Formation of ions as a particle identity are not commonly considered. For the few studies that considered ions, their features that could influence the complexity of drawing reactions were not explored. Finally, these previous studies were found to account for the visual elements of the drawings but not the spatial relationships between them.

2.1.6 How are Freehand Drawings of Chemical Reactions at the Submicroscopic Level Assessed?

If students were taught using drawing, then they too should be assessed via drawing (Johnson & Reynolds, 2005). Learning from drawing as a teaching-learning strategy should be assessed via drawing. Tang et al. (2019) assessed students' drawing of chemical bonding using three types of meaning created in a semiotic system: (1) Presentational, (2) orientational and (3) organisational. These three meanings are operationalised into seven broad categories.

- i. Presentational meaning relates to presenting the ideas and experiences of the world. Categories for presentational meaning include (a) association, which refers to how visual objects are put together, e.g., not joined together, connected through lines, boundaries touching, boundaries overlapping, or drawn within a larger object; (b) spatial, which refers to the spatial relationship between visual objects, e.g., position, alignment, spacing, distribution, relative size, and relative scale; and (c) movement,

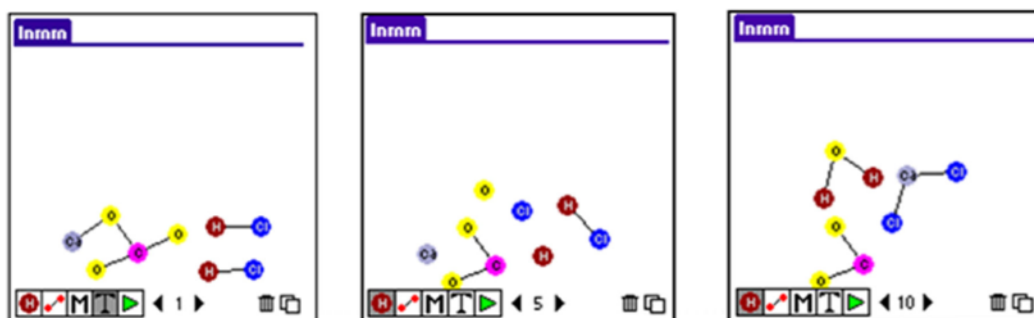
which refers to how dynamic actions of visual objects are depicted, e.g., arrow, path line, wavy lines, and no movement. In the context of drawing of chemical reactions at the submicroscopic level, some of the above features are more relevant than others. Those that are more relevant are association and spatial. The association category can be used to describe the identity of the particles involved in a chemical equation, e.g., atoms, ions, or molecules. The spatial category can be used to describe the phases of the constituent chemical species (s, l, aq or g) and their types (e.g., crystalline, or amorphous solid) based on the arrangement and distance between particles.

- ii. **Orientational meaning** relates to how the viewer of the drawing interacts, views, or relates with the presented ideas. Categories for orientational meaning include (d) perspective, which refers to how visual objects are depicted based on the viewer's point of view, e.g., dimension, angle, and abstraction (macroscopic, microscopic, and symbolic); and (e) modality, which refers to the credibility of how the visual objects are depicted, e.g., cartoonish, iconic, schematic, shades, or sharp lines. Both perspective and modality categories are relevant in the context of drawing of chemical reactions at the submicroscopic level. With perspective, the drawing serves as a symbolic abstraction of the submicroscopic processes involved in a macroscopic phenomenon. For modality, drawing of chemical reactions are not for replicating the physical appearance of submicroscopic entities but to represent their important structural and spatial features (schematic).
- iii. **Organisational meaning** relates to organising elements of the drawing and condensing them into a coherent system. Categories for organisational meaning include (f) connective, which refers to how smaller elements of a complex diagram are linked logically, e.g., via temporal sequence or comparison; and (g) textual, which refers to the use of text to give contextual meaning to the visual object, e.g., label, legend, and

caption. Both connective and textual categories are relevant in the context of drawing of chemical reactions at the submicroscopic level. For connective, comparing what happens before and after the chemical reactions (i.e., changes from reactants to products) can be used to demonstrate temporal sequence. With textual, adding labels, legend, and written description helps the viewer to better make sense of the drawing.

Most studies of students' drawings of chemical reactions assessed them as spatial rearrangement of particles (Chang et al. 2014; Davidowitz et al. 2010; Kern et al. 2010; Ryan and Stieff, 2019; and Yaroch, 1985). The interaction of electrons and formation of ions are usually not considered. For example, in the study of Chang et al. (2014), students during the interview were asked to produce a computer drawing of their understanding of the molecular process of the reaction between hydrochloric acid and calcium carbonate. Although both reactants and one (i.e., calcium chloride) of the three products (the other two are water and carbon dioxide) are present as ions in solution, they were drawn as atoms and molecules as shown in Figure 2.

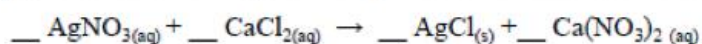
Figure 2 *Student's Drawing of the Chemical Reaction Between Hydrochloric Acid and Calcium Carbonate Producing Calcium Chloride, Water and Carbon Dioxide (Chang et al. 2014)*



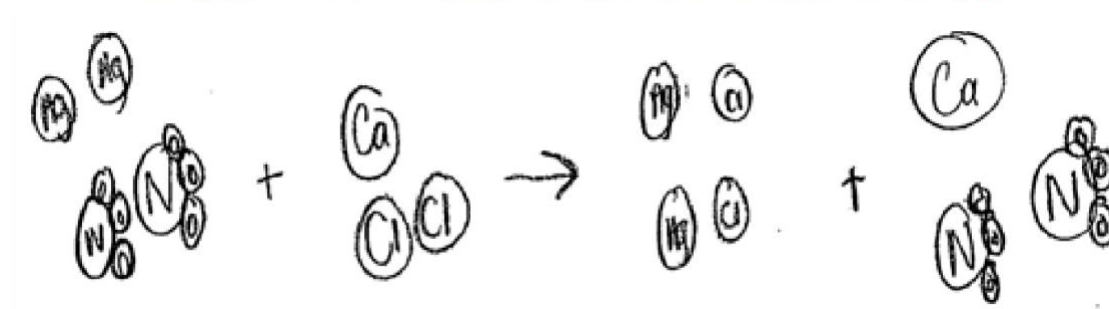
There are, however, few studies that considered the formation of ions as identity of the particles in assessing students' drawings of reactions (Cheng, 2018; Cheng and Gilbert, 2017; and Nyachwaya et al., 2011). Figure 3 presents a student's drawing from the study of Nyachwaya et al. (2011). The chemical reaction is between silver nitrate and calcium chloride producing silver chloride and calcium nitrate.

Figure 3 *Student's Drawing of the Chemical Reaction Between Silver Nitrate and Calcium Chloride Producing Silver Chloride and Calcium Nitrate (Nyachwaya et al., 2011)*

Silver Nitrate (AgNO_3) reacts with Calcium Chloride (CaCl_2) to form Silver Chloride (AgCl) and Calcium Nitrate ($\text{Ca}(\text{NO}_3)_2$). The reaction is represented by the *unbalanced* chemical equation below:



- Write the appropriate numbers in the blanks to balance the chemical equation
- In the space below, draw diagrams that represent what you think you might see if you were able to see the atoms, molecules or ions involved in the chemical equation above. Remember to draw the correct number of atoms, molecules or ions of each reactant and each product.



The drawing in Figure 3 was tagged as conceptually inaccurate in terms of the identity of the particles involved in the chemical reaction. Using the chemical equation as a guide, the student drew aqueous AgNO_3 as one silver atom and one nitrate molecule (one nitrogen atom and three oxygen atoms); aqueous CaCl_2 as one calcium atom and one diatomic chlorine molecule (two chlorine atoms); aqueous AgCl (should be solid instead) as one silver and one chlorine atom; and aqueous $\text{Ca}(\text{NO}_3)_2$ as one calcium and two nitrate molecules. Although the particles are shown as dissociated entities, charges were not assigned to them to indicate that they are ions. Moreover, the number of particles of each chemical species were checked

to see if it concurs with the lowest possible ratio of coefficients for a balanced chemical equation, which is 2:1:2:1. In other words, the drawing in Figure 3 was assessed in terms of its visual elements, i.e., identity of the particles and conservation of particles.

Additionally, both Cheng (2018), and Cheng & Gilbert (2017) suggested that there are two models that students used to understand chemical reactions. These two models are the particle model and the atomic model. In the particle model, reactant particles simply undergo spatial rearrangement to form the product and there is no particle identity transformation (atoms, molecules or ions remain as atoms, molecules, and ions, respectively). In the atomic model, the activity and interaction of the electrons are considered. There is transformation in the identity of the particles (i.e., atoms and/or molecules becoming ions or vice versa) and formation of ions is recognised. The atomic model accounted for both spatial rearrangement and changes in particle identity. Cheng (2018), and Cheng & Gilbert (2017) further noted that fewer challenges are experienced by students when using the particle model compared to the atomic model. Students prefer to think of atoms as concrete, discrete entities (making up matter) and not involving abstract process ideas (Harrison & Treagust, 1996); and this is probably because chemistry instruction largely represents ‘atoms’ as indivisible entities (Taber, 2003) even if they are not (since they are made up of subatomic particles). In fact, several chemistry textbooks use the particle model rather than the atomic model to illustrate chemical reactions (Chang, 1994, p. 84, Hill & Petrucci, 1996, p.84, and Rendle, n.d., p. 121-123). Atoms are shown as indivisible, discrete entities that simply rearranged during chemical reaction (Atkins, 2013, p. 46).

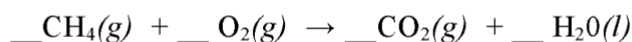
The studies of Cheng, 2018; Cheng and Gilbert, 2017; and Nyachwaya et al., 2011 did recognise the formation of ions in drawing chemical reactions. However, complexities in drawing these ions were not explored. Features of these ions (e.g., monatomic, or polyatomic, charges, and/or number of atoms as indicated by the subscripts) can influence students’

difficulties in drawing them. It is also notable that those previous studies mentioned predominantly assessed only the visual elements (i.e., identity and conservation of particles) of the drawings. The spatial relationship between these visual elements, that is the arrangement of the particles and the distance between them based on the phases of the chemical species, were left out. One study has been found that assessed the spatial elements of students' submicroscopic drawings of chemical reactions. Ryan and Stieff (2019) analysed the spatial elements of students' submicroscopic drawings of chemical reactions in terms of the 'position' of the particles to show its phase (i.e., solid, liquid or gas). However, it was not clear whether 'position' refers to the arrangement of the particles (e.g., regularly or irregularly stacked) or distance between the particles (e.g., closely packed or separated with wide empty spaces). These two spatial features describe two different ideas in drawing chemical reactions. For example, drawing magnesium oxide made up of ions close to each other represents it as a solid. Yet a solid can either be crystalline (regularly stacked above each other) or non-crystalline (irregularly stacked above each other). Examining the drawing of magnesium oxide in terms of distance between particles but not by arrangement of particles does not accurately exemplify magnesium oxide as a solid ionic crystal.

Furthermore, it is vital that spatial elements are examined because submicroscopic drawings of chemical reactions can be visually accurate but spatially inaccurate. For example, Figure 4 presents a student's drawing of the combustion of methane, producing carbon dioxide and water from the study of Kern et al. (2010). The drawing is tagged as a 'balanced particulate representation with discrete atoms'. This is because the molecules are drawn with the correct number and connectivity of constituent atoms (identity of the particles). The molecules match with the chemical formulae in the chemical equation (linking with chemical equation). Additionally, mass conservation is shown correctly (conservation of particles) based on a balanced chemical equation, $1:2:1:2$ (linking with chemical equation).

Figure 4 *Student's Drawing of the Combustion of Methane (Kern et al., 2010)*

Methane gas (CH₄) reacts with oxygen gas (O₂) to produce carbon dioxide (CO₂) and water (H₂O). This reaction is represented by the unbalanced chemical reaction below:



Write the appropriate numbers in the blanks to balance the chemical equation.

In the space below, draw diagrams that represent what you think you might see if you were able to see the atoms and molecules involved in the chemical reaction above. Remember to draw the correct number of atoms and molecules for each reactants and each product.

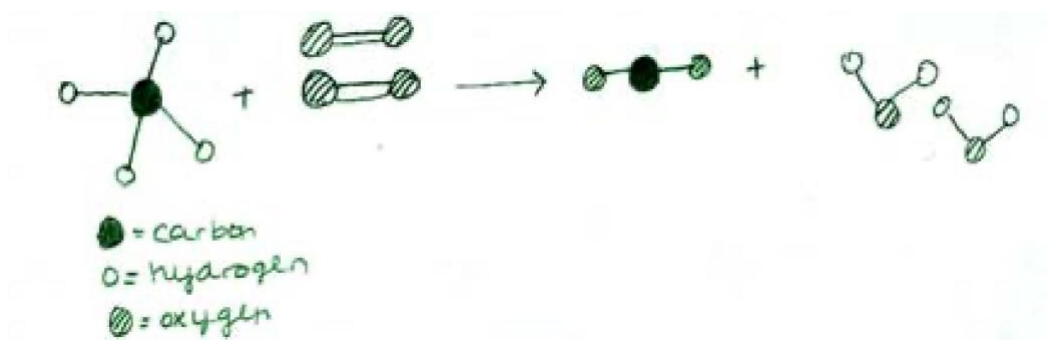


Figure 4 shows that the identity of methane, oxygen, carbon dioxide and water are correctly drawn as molecules and are conserved (visual elements). However, the spatial elements of the drawing, i.e., arrangement and distance between particles are not examined. No distinction was made between the gaseous (methane, oxygen, and carbon dioxide) and liquid (water) substances. More molecules of methane, carbon dioxide and perhaps oxygen and water should be drawn. The liquid molecules should be arranged as irregularly scattered with little empty spaces whereas gaseous molecules should have wide empty spaces between them. If drawing is to be used to cultivate conceptual understanding of chemical reactions, students should be supported to include the pertinent conceptual ideas represented as both visual elements and spatial relationships between these elements.

Finally, previous studies of students' drawings of chemical reactions assessed drawings qualitatively. Qualitative analysis of drawings usually involves asking domain experts to identify the essential conceptual ideas about the chemical reaction. These essential conceptual ideas are marked as represented elements of the drawing (Leopold & Leutner, 2011; Leopold et al., 2013). The drawings are coded for the presence or absence of these elements and their relationships (Akaygun & Jones, 2014; Kunze & Cromley, 2021). Qualitative analysis, however, has no provision for scoring. Instead, quantitative analysis enables the assignment of scores to the drawings which can be used as a measure of student learning achievement. These scores can be used to compare the quality of drawings and hence student learning achievement within the class or between classes.

2.1.7 What are the Visual and Spatial Elements of Freehand Drawing of Chemical Reactions at the Submicroscopic Level?

In this section, in view of the limitation of existing studies in assessing student drawings (in particular, the lack of attention to the spatial elements of drawings), I propose a visual-spatial assessment framework for drawing chemical reactions. The visual elements and their spatial relationships (spatial elements) as shown in the drawing were used to evaluate students' submicroscopic ideas of the chemical reactions.

The chemical species are represented with a specific shape (usually circle) and colours or shades to distinguish their identities. The shape, colours and shades are elements of the drawing that could be categorised as visual (Farah et al., 1988; Knauff, 2013; Reisberg & Heuer, 2005; Sima et al., 2013; Surtees et al., 2013) because they are concerned with (1) "what is the appearance of the represented entities?" e.g., circles as representation of particles, and (2) "what are the identities of these represented entities?". In Figure 3, circles are drawn to represent each atom. Chemical symbols written inside the circles are used to label the atoms of silver (Ag), calcium (Ca), and chlorine (Cl). A cluster of circles with

chemical symbols for nitrogen (N) (one circle) and oxygen (O) (three circles) is used to represent nitrate as a molecule (combination of two elements with no charge assigned) or a pair of bonded circles with the chemical symbol for chlorine (Cl) to represent the diatomic molecule.

Additionally, the chemical species in the drawing have a certain arrangement, position/location, and distances between parts of them or between other chemical species. These arrangements, positions/locations and distances can be categorised as spatial relationships or spatial elements (Farah et al., 1988; Knauff, 2013; Reisberg & Heuer, 2005; Sima et al., 2013; Surtees et al., 2013) because they are concerned with the question: “Where should these represented chemical species (or parts of them) be positioned or located relative to the other chemical species within that drawing space?”. In Figure 3, atoms of silver, calcium and chlorine, and molecules of nitrate are scattered in a regular pattern. For silver nitrate, the two silver atoms are above the two nitrate molecules. For silver chloride, the two silver atoms are on the left side of the two chlorine atoms. Table 2 presents a list of elements of the student’s drawing in Figure 3 and their classification as either visual or spatial.

Table 2 *Elements of the Drawing in Figure 3 Classified as Either Visual or Spatial*

	Element	What it/they represent (Essential conceptual idea units)	Visual	Spatial
1	A circle labelled as ‘Ag’	A silver atom	✓	
2	‘Ag’ circles regularly scattered	A part of silver dissolved in solution		✓
3	‘Ag’ circles with spaces around them	A part of silver in the aqueous phase		✓
4	Circles labelled as ‘N’ and ‘O’	Nitrogen and oxygen atoms	✓	
5	One ‘N’ and three ‘O’ circles clustered together	A nitrate molecule	✓	
6	The clustered one ‘N’ and three ‘O’ circles are	A part of nitrate dissolved in solution		✓

	accurately scattered (e.g., N but not O being the central atom)			
7	The clustered one 'N' and three 'O' circles with spaces around them	A part of nitrate in the liquid phase		✓
8	A circle labelled as 'Cl'	A chlorine atom	✓	
9	'Cl' circles regularly scattered	A part of chlorine dissolved in solution		✓
10	'Cl' circles with spaces around them	A part of chlorine in the liquid phase		✓
11	A circle labelled as 'Ca'	A calcium atom	✓	
12	A 'Ca' circle appeared scattered just like 'Cl' circles and 'NO ₃ ' clusters	A part of calcium dissolved in solution		✓
13	A 'Ca' circle with spaces around it	A part of calcium in the liquid phase		✓
14	The number of 'Ag', 'Cl', 'Ca' circles and 'NO ₃ ' clusters before the reaction is the same as the number of circles and clusters after the reaction	Law of Conservation of Mass (or Particle) is observed	✓	

Visual Elements. I would like to highlight that the drawings shown in Figures 3 and 4 are not entirely conceptually accurate. They serve to exemplify visual and spatial elements. Elements 1, 4, 5, 8 and 11 refer to the identities of the particles of the represented chemical species involved in the chemical reaction. Elements 1, 4, 5, 8 and 11 are visual elements. The circular shape and annotations (e.g., chemical symbols as labels) are assigned to aid in representing silver, nitrogen, oxygen, calcium, and chlorine particles. These visual details for silver, calcium, and chlorine may mean that the student thinks that these particles are atoms. The cluster of nitrogen and oxygen shows that the student may think that nitrate is a molecule. The cluster of nitrogen and oxygen is categorised as visual because no matter how each NO₃ molecule is oriented in the paper, the identity of nitrate as a molecule made up of one nitrogen and three oxygen atoms is not affected. Details on the charges should have been

added to accurately show that silver, calcium, and chlorine are monatomic ions, and nitrate is a polyatomic ion.

Element 14 refers to the conservation of particles, which is also categorised as visual. Conservation of particles involves looking and counting the number of particles of the reactants (before the reaction) and products (after the reaction), which is supposed to be equal. For the chemical reaction between silver nitrate and calcium chloride producing silver chloride and calcium nitrate as shown in Figure 3, the conservation of particles is based on the ratio expressed in the balanced chemical equation, $2\text{AgNO}_3 + \text{CaCl}_2 \rightarrow 2\text{AgCl} + \text{Ca}(\text{NO}_3)_2$, which is 2:1:2:1. The number of particles from both sides of the chemical equation is not affected by how each chemical species is oriented or positioned in the paper.

Spatial Elements. Elements 2, 6, 9 and 12 refer to the arrangement of the particles of the chemical species involved in the chemical reaction. The arrangement of particles as an element of the drawing is categorised as spatial because it considers how each particle (represented as a circle) is positioned relative to other particles within the drawing space. For example, in Figure 3, silver, chlorine, calcium and nitrate particles are scattered suggesting that they are in solution. In Figure 4, oxygen (O_2) and water (H_2O) molecules are also scattered. Such arrangement suggests that oxygen and water are fluids not solids. Methane (CH_4) and carbon dioxide (CO_2) are drawn as one molecule each. Hence, it is not possible to infer from the drawings the phases of methane and carbon dioxide. Different spatial arrangements represent different things. Further examples include particles that are regularly stacked above each other representing crystalline solids, i.e., metal, or ionic crystal. Particles irregularly stacked above each other might represent liquid or an amorphous solid. For Figure 3, silver chloride should have been drawn as particles of silver and chlorine particles that are regularly alternating and regularly stacked above each other. Silver chloride is present as a solid ionic crystal not as an aqueous solution. Additionally, silver nitrate, calcium chloride

and calcium nitrate particles should have been drawn as irregularly scattered. The same goes for the oxygen and water molecules shown in Figure 4. Oxygen and water molecules should have been drawn as irregularly scattered.

Elements 3, 7, 10 and 13 refer to the distance between particles of the chemical species involved in the chemical reaction. Distance between particles is considered spatial because it is concerned with how the represented chemical species (or parts of them) are positioned or located relative to the drawing space and to other chemical species within that drawing space. The distances between particles are used to depict their phases. In Figure 3, the particles of silver nitrate, calcium chloride, calcium nitrate and silver chloride have spaces around them that are not too wide suggesting that they are in the liquid phase. Nevertheless, it is essential to point out that silver chloride is solid. Hence, it should have been drawn as atoms touching or close to each other. In Figure 4, oxygen and water molecules also have spaces between them. However, a distinction cannot be made between gas and liquid because the spaces appear the same. Oxygen molecules being a gas should have wider empty spaces among them than water molecules being a liquid. For methane and carbon dioxide, more molecules should be drawn with wide empty spaces comparable to oxygen molecules to show that they are gases.

This proposed visual-spatial assessment framework could advance how students' submicroscopic drawings of chemical reactions are assessed. Existing studies have predominantly examined students' drawings of chemical reactions for their visual elements (i.e., identity of the chemical species and conservation of particles) only. Spatial elements are either vaguely assessed or left out. The proposed visual-spatial assessment framework offers a way to include two spatial elements, i.e., arrangement and distance between particles (and its associated conceptual ideas) in assessing students' drawings. Additionally, the proposed framework can potentially reveal students' difficulties in drawing certain visual and spatial

features, which consequently can reveal students' challenges in understanding chemical reactions at the submicroscopic level. The proposed framework may serve as an interpretive lens to make sense of the students' conceptual ideas about chemical reaction.

2.2 Feedback

From Section 2.1.3, it has been recognised that feedback has an essential function during drawing as a teaching-learning strategy. Feedback can be used by students to check the quality of their drawings and mental models. High quality feedback needs to attend to many aspects of drawing a chemical reaction at the submicroscopic level, i.e., visual-spatial elements of the drawing, verbal linkages to the drawing, triplet relationship and prerequisite chemistry knowledge. I want to investigate how teachers and students' peers attend to these *feedback foci*, how they are delivered (*feedback moves*), and their impact on learning.

This section presents a literature review on feedback. The section begins by describing feedback in the context of developing scientific understanding using diagrams. Several conditions are identified, which may affect the effectiveness of feedback. A presentation of the different categories of feedback used in the classroom characterised the feedback used in the intervention. In this study, two sources of feedback on students' submicroscopic drawings of chemical reactions were investigated: Teacher-feedback and peer-feedback. These two feedback sources present distinct characteristics. On the one hand, teacher-feedback is viewed as one-way, i.e., the teacher is the principal source of feedback for the students. On the other hand, peer-feedback is regarded as reciprocal, i.e., students take turns in their roles as assessors and assessees. Based on these characteristics, the ICAP (*Interactive, Constructive, Active and Passive*) theory (Chi, 2009, 2021; Chi & Wylie, 2014) is offered as a framework to describe students' engagement with teacher-feedback and peer-feedback on drawing chemical reaction. The ICAP theory has been used to characterise different classroom activities (e.g., note-taking, reading comprehension, concept mapping,

whole-class and small-group discussions, lecture, group work, self-explanation, and problem solving, among others) but not for feedback on drawing. The link between the interaction of feedback source (including student engagement) and drawing is not well-established in the literature.

2.2.1 What is Feedback?

Feedback in the context of teaching and learning is defined by varied authors as either the information (Hattie & Timperley, 2007) or the process of giving information (Dawson et al., 2019) by an agent (i.e., teacher, students' peers, parent, book, self, or experience) to a learner's output or performance after instruction. The information is used to identify the strengths and weaknesses of the output or performance to help improve subsequent ones (Hattie & Timperley, 2007; Kluger & DeNisi, 1996). Hence, feedback is an outcome of performance (Hattie & Timperley, 2007). In terms of identifying the strengths of a learner's output or performance, feedback can be used to affirm those strengths. Doing so can keep the learner continuously persisting with those strengths (Sadler, 2010). For identifying weaknesses, feedback should not only be used to identify those weaknesses but also to fill in any discrepancies between the expected and the actual output or performance (Sadler, 2010). Identified discrepancies serve as the basis to enable the feedback-receiver to take corrective actions (Schneider et al., 2018; Tsivitanidou et al., 2011), which can guide towards improved future output or performance. Feedback can tell a student (a) the goal or standard for the output or performance (feed-up); (b) the status of his/her current output or performance relative to the goal or standard (feed-back); and (c) the gaps between his/her current output or performance and the goal or standard including how to close those gaps (feed-forward) (Hattie & Timperley, 2007). Such standards should be specific to help focus the student's attention onto how those standards can best be met (Hattie & Timperley, 2007).

Feedback is linked to scaffolding. As a teaching method, scaffolding involves providing support and guidance that is responsive to the state of abilities and understanding of the students. This support and guidance are gradually removed to allow for greater independence of the students (Oh, 2005). From this description, scaffolding has three characteristics: (a) contingency, which refers to the support given based on the current level of students' needs and abilities; (b) fading, which refers to the gradual withdrawal of support. Fading leads to (c) transfer of responsibility, which refers to students being independent and competent at accomplishing the task (van de Pol et al., 2011). Scaffolding as a teaching method is anchored to what Vygotsky (1978) describes as the Zone of Proximal Development (ZPD). It is within the ZPD where learning occurs for a task that a student cannot do yet but is within his reach when guidance is provided (van de Pol et al., 2011) by a 'knowledgeable other'. The 'knowledgeable other' is someone who has more expertise compared to the student (e.g., teacher or a more capable peer). Through social interaction, the 'knowledgeable other' can provide mediation to bridge the gap between the student's actual development level and level of potential development (Vygotsky, 1978). To illustrate how feedback on submicroscopic drawings of chemical reactions is related to scaffolding: the teacher (or a more capable peer) provides feedback on a drawing that is contingent on the submicroscopic ideas represented. The teacher identifies any discrepancies between the student's actual drawing and the canonical drawing. The teacher provides direction to improve the actual drawing relative to the canonical one. This direction from the teacher can be used by the student to be more independent and competent in the subsequent drawing tasks.

Feedback comes after an output or performance is given (Hattie & Timperley, 2007). Scaffolding, on the other hand, can precede an output or performance of new understanding (Oh, 2005). An example of scaffolding preceding an output would be a teacher modelling how to construct submicroscopic drawings of chemical reactions. And the teacher may use

prompts to provide a structure to assist students to elicit the desired submicroscopic drawing of chemical reactions. Both teacher modelling and prompts can be implemented without students having to try drawing in the first place. Both scaffolding and feedback can be implemented in a structured way (Chang and Chang, 2013; Tsivitanidou et al., 2011).

Windschitl et al. (2018) suggested four scaffold prompts that reflect how scientists change scientific models. According to Windschitl et al. (2018), these scaffold prompts can be used in a science classroom: ‘Adding an idea’, ‘removing an idea’/‘finding out more about the idea’, ‘revising an idea’ and ‘posing a new question’. Additionally, it has been found that receiving justified feedback comments improves performance (Gielen et al., 2010a). A study was conducted by Chang and Chang (2013) among Taiwanese Grade Eight students on their ability to critique molecular diagrams of reactions. A structure for critiquing the molecular diagrams was provided. The criteria and premade comments were made available. The structure made the complex task of critiquing the molecular diagrams of reactions accessible for the students. In science, Sheredos and Bechtel (2017) identified that feedback from peers helped biologists studying the circadian rhythm in cyanobacteria (*Synechococcus elongatus*) refine their biological diagrams. These biological diagrams were used to provide a coherent understanding and explanation of the interaction and variation of the components and mechanism of the circadian rhythm. From both the studies of Chang and Chang (2013), and Sheredos and Bechtel (2017), feedback contributed to a better understanding of scientific ideas through diagrams for both students and scientists. Feedback can then be considered as a valuable tool in assisting performance.

The effectiveness of feedback depends on several conditions including characteristics of the following: feedback, instruction, feedback source (i.e., teacher and student-peers), and social and interpersonal variables (Panadero et al., 2018). Feedback characteristics include whether qualitative comments or quantitative marks are used and whether feedback is

focused on the self-level, task-level, process-level or self-regulation level (Hattie & Timperley, 2007). Timeliness is also an important feedback characteristic. Shute (2008) claimed that when a learner is involved in completing a task beyond his/her current capability, immediate feedback is good. During new task acquisition, immediate feedback contributes to faster rates of acquisition because errors are immediately identified and corrected (Hattie & Timperley, 2007). When a learner has a task within his/her current capability delayed feedback is good (Shute, 2008). Delaying the feedback provides a window for greater degree of processing the task and building proficiency on it (Hattie & Timperley, 2007).

Characteristics of instruction have also been identified as a condition that impacts the effectiveness of feedback. Examples include the nature of the learning context (e.g., learning goals, learning tasks, and learning materials) and potential sources of difficulties. For feedback to accomplish its purpose it should be given within a learning context. Feedback does not occur in a vacuum (Hattie & Timperley, 2007). Feedback is based on what the learning context is all about, i.e., what is the learning task, and what is its goal, what are the materials used to accomplish the goal, and what are the challenges that may hinder the feedback activity. Receiving instructional support during feedback is another characteristic of instruction. Examples of instructional support include scaffolds, rubrics, prompts, practice, and training. Instructional support contributes to the reliability and validity of the feedback (Tsivitanidou et al., 2011).

The characteristics of instruction as a factor influencing feedback effectiveness relates to the ecological (Chong, 2021) and socio-material (Gravett, 2020; Nieminen et al., 2022) perspectives on students' uptake of feedback. From an ecological perspective, the learning context mediates student's engagement with the feedback (Chong, 2021). From a socio-material perspective, material (e.g., freehand drawings) and symbolic (e.g., dialogues)

artefacts also mediate a student's feedback uptake (Gravett, 2020; Nieminen et al., 2022).

Combining the two perspectives: within the learning context exists not only human-human (i.e., teacher-student and student-student) but also human-non-human (e.g., student-freehand drawing) interactions. Both these human-human and human-non-human interactions influence how students make sense of feedback. A student's agency in feedback involves both social and material considerations (Gravett, 2020). In sum, feedback is a communicative event between individuals with distinct characteristics (social agency) impacted by the affordances and limitations of the learning materials (material agency) within a specific context (Nieminen et al., 2022).

In the Philippines, class sizes are usually larger and more crowded (~50) compared to other Asian countries, i.e., Malaysia is 34, Thailand is 42, Japan is 34 and India is 39 (Class Size and Conditions Act, 2022). Large class sizes, however, present challenges to learning. According to Roberts (2007), lower achievement gains are associated with large classes particularly in the upper grades. Additionally, feedback tends to be less frequent and generalised in large classes due to time constraints compared to regular and detailed feedback in smaller classes.

Previous studies have identified varied strategies on how to give useful feedback in large classes (Rodríguez et al., 2022; Søndergaard & Thomas, 2004; Xu & Harfitt, 2019). These strategies can be classified into two themes: Technology-facilitated and use of student-feedback. Technology and student-feedback have been found useful because they help provide timely feedback, support fair feedback provision for each student (every student has the same opportunity to receive feedback), and facilitate student interaction (or discussion) that may lead to the creation of new understanding (Rodríguez et al., 2022; Søndergaard & Thomas, 2004; Xu & Harfitt, 2019). On implementing feedback to support drawing to learn chemical reactions in large classes, I have found no previous studies that explored what

feedback features are useful. Knowing these useful feedback features may help relieve the challenges in implementing feedback in large classes.

Most teaching-learning activities in the Philippines are teacher-centred and the teacher's authority in the classroom is culturally valued by the learners (Del Valle, 2020, 2022 & 2023). The students perceived teacher-centred instruction as a good teaching practice because they consider it as an act of academic care (Del Valle, 2020, 2022 & 2023). Education is highly valued among Filipino students because it is instrumental in achieving their personal life goals and in securing a better future (Jocano, 1997). Consequently, the teacher's authority in the classroom is valued and respected for its crucial role in helping students to succeed in their education (Del Valle, 2020, 2022 & 2023). In large classes (like the Philippines) the teacher is recognised to have a central role in promoting assessment for learning in the classroom (Xu & Harfitt, 2019).

Further, Panadero et al. (2018) identified characteristics of the teacher and students as feedback source, and social and interpersonal variables that impact the efficacy of feedback. The teacher and students as feedback providers have been found to present different characteristics, which affect the quality of feedback (Tsivitanidou et al., 2011). On the one hand teachers are domain experts. Student-peers, on the other hand, are novices who struggle with the same learning objectives and difficulties. Student-peers also share the same language. And since a reciprocal relationship exists between the assessor and assessee during peer-feedback, both of their characteristics are equally important. Social and interpersonal variables include issues of trust during feedback reception and anonymity (Panadero et al., 2018). Students tend to trust their teachers over their peers because teachers are domain experts and authority figures. But most students preferred non-anonymous teacher-feedback. In terms of peer-feedback, there is no difference in feedback quality in the anonymous and

non-anonymous phases. Anonymity helps the feedback provider (i.e., to be objective in his/her assessment) but not the recipient of the feedback (Panadero et al., 2018).

Feedback plays a powerful role in the development of students' self-regulation and learning (Butler & Winne, 1995; Hattie & Timperley, 2007; Hill & Edwards, 2019). When a student receives feedback, he/she makes sense of it and implements it (Carless & Boud, 2018). He/she can choose to change his/her behaviour, change the goal, abandon the goal, or reject the feedback (Kluger & DeNisi, 1996). Furthermore, assisting students' performance through feedback is not simply acknowledging that the performance is right or wrong. Feedback is more than just supplying the correct answer after a student's incorrect response (Brookhart, 2018). Feedback has a formative assessment function (Hattie & Timperley, 2007; Peterson & Irving, 2008). Feedback bridges the gap between the current performance and the standard. Such bridging can guide the student in improving his/her subsequent performance. The next section presents the different forms of feedback used in the classroom.

2.2.2 What are the Different Forms of Feedback Used in the Classroom?

To provide a systematic view of the forms of feedback used in the classroom, I organised these feedback forms into two categories as follows: (1) the format of feedback and (2) the source of feedback. Each feedback form presents certain characteristics, which determine their affordances and limitations. One form of feedback based on the format may overlap with another based on the source. For example, face-to-face feedback (based on the format) can be from the teacher (based on the source).

Format of the Feedback. Based on the format, feedback can be described as (a) paper-based or computer-based; (b) if computer-based: online or off-line; (c) one-way or reciprocal; (d) supported or unsupported (Tsivitanidou et al., 2011); and (e) face to face or written (Bedford & Legg, 2007). The supported form is when students receive support before and during the implementation of the feedback. This support can be in the form of a structure

on how to go about delivering the feedback or training for implementing it. The unsupported form is when structure or training are not provided to the students (Tsivitanidou et al., 2011). Another form of feedback based on format is face to face. This feedback form is highly valued by students because of the establishment of human connection. Face to face feedback is personalised, dynamic, genuine, and generates high-quality interactions. The assessor and assessee can discuss clarifications and details of the feedback. According to students, hearing the voice of the assessor and seeing them deliver the feedback help them develop a deeper understanding of the feedback (Killingback et al., 2020). More so, students usually consider their teachers (as assessors) as models. So, if the teacher is emotionally detached from the learning situation (e.g., when computers are used to give feedback), students will also be emotionally detached (Dreyfus & Dreyfus, 2005).

Source of Feedback. Generally, in classrooms, feedback will be teacher-generated, peer-generated, or self-generated (Bedford & Legg, 2007; Cho & MacArthur, 2010; Coenders, 2016; Repice et al., 2016; Strijbos & Sluijsmans, 2010; Topping, 2010; Tsivitanidou et al., 2011). Self-generated feedback is described as internal feedback generated by the student him/herself. Teacher-generated and peer-generated feedback are considered external feedback, i.e., feedback from knowledgeable others (Chou & Zou, 2020). In Section 2.1.3, the provision of external feedback on drawing is valuable. External feedback can be used by students to evaluate the drawing and the mental model that goes along with it. Teacher-generated feedback (or simply teacher-feedback) and peer-generated feedback (or simply peer-feedback) are further described by Tsivitanidou et al. (2011) as: Teacher-feedback is usually referred to as a one-way or elite source of feedback. The teacher acts as the assessor and the students are the assessees. The teacher who is usually regarded as the expert is the prime (if not only) source of feedback. Alternatively peer-feedback involves students assessing each other and this usually referred to as reciprocal or egalitarian source of

feedback (Tsivitanidou et al., 2011). The students themselves are the sources of feedback. The students act both as assessors and assessees (Bedford & Legg, 2007; Cho & MacArthur, 2010; Repice et al., 2016; Tsivitanidou et al., 2011).

Teacher-feedback and peer-feedback appear as two effective sources of external support. Both sources play a complementary role and are needed (Wu et al., 2022). When used together, teacher-feedback and peer-feedback are effective (Gielen et al., 2007; Hill & Edwards, 2019). But using them separately may yield different results since each feedback source present distinct characteristics that determine their affordances and limitations. Comparing them demonstrates a comparison between two effective tools.

Variable results were reported in the literature that compared the usefulness of teacher-feedback and peer-feedback in supporting writing to learn. I have identified two sets of studies. The first set reported that teacher-feedback was deemed more useful by students than peer-feedback (Paulus, 1999; Ruegg, 2015; Tajik et al., 2016; and Yang et al., 2006). In these studies, teacher statements and questions improved writing content better than peer-feedback (Tajik et al., 2016). The second set of studies described that peer-feedback is comparable, if not better than teacher-feedback (Cho et al., 2008; Cho & MacArthur, 2010; Yangin Eksi, 2012; and Gielen et al., 2010b). The two sets of studies had similar feedback *foci*, i.e., either content, technical or both components of students' written work. Hence, it appeared unclear why there is variability in the findings. However, the context of the studies, particularly how the student-participants value their teachers or peers' authority in giving feedback and how it can potentially influence feedback uptake, are not considered. The first set of studies had largely Asian students, i.e., Chinese, Japanese, Iranians (Paulus, 1999; Ruegg, 2015; Tajik et al., 2016; and Yang et al., 2006) who are more used to teacher-dominated classrooms than the Western counterparts, i.e., the USA, Belgium, and Turkey (partly European) from the second set of studies (Cho et al., 2008; Cho & MacArthur, 2010;

Yangin Eksi, 2012; and Gielen et al., 2010b). The following section explores in greater detail the characteristics of these two feedback sources.

2.2.3 What are the Differences between Teacher-Feedback and Peer-Feedback in Supporting Learning?

This section describes the characteristics of teacher-feedback and peer-feedback. These characteristics determine their uses and limitations in supporting learning. Towards the end of this section, I presented how the two feedback sources are used to support learning in science.

Teacher-feedback. Teacher-feedback on students' work has been identified as one of the most powerful forms of support for classroom learning (Brookhart, 2018). The teacher is considered as the expert because of his/her broad domain knowledge and experiences. Such expertise and experience in marking students' work cannot easily be equaled (Sadler, 2009) and students do recognise such authority and expertise. Students also think that the teacher can provide more accurate feedback ideas (Cho & MacArthur, 2010) and consider that the time spent on feedback is well-invested (Coenders, 2016). Consequently, students tend to give weight and act on the teacher's viewpoint (Killingback et al., 2020).

In some instances though, the teacher's advanced level of domain knowledge can be a disadvantage in feedback. Teacher-feedback can lower students' ability to detect errors in their own work because they assume that the teacher as the domain expert had addressed all the errors. Hence, students do not need to confirm if further corrections are needed (Gielen et al., 2010a; Yang et al., 2006). The teacher (depending on his/her pedagogical content knowledge) may also use knowledge that is unavailable to students. For example, the teacher may include jargon in his/her feedback that students may not easily understand and so students may find the feedback less comprehensible to implement (Cho & MacArthur, 2010). The teacher may also underestimate the difficulty level of the task for the students (Cho &

MacArthur, 2010; Topping, 2010). In Cho & MacArthur's (2010) study, they found that the writing quality of undergraduate psychology students who received teacher-feedback during an intensive writing course on research methods was associated with poorer performance than those who received peer-feedback. The teacher in the study was a subject-matter expert in writing (i.e., having a PhD in writing, taught similar writing courses and topics for eight years, and teaching skills within the top 35%) but his/her feedback led students to make only simple revisions and failed to improve text complexity. Additionally, students who were asked to add new content to their written text made it worse. In the study, the students appeared to have misunderstood the teacher-feedback.

The teacher being a domain expert can also have negative impacts on the affective aspects of feedback. Teacher-feedback is associated with low psychological safety (the low belief that the environment is safe from interpersonal risks) and high-value diversity (the low agreement between the assessor and assessee about the assessee's performance) (Topping, 2010). This might be because the teacher being the ultimate source of feedback allows limited discussion with students to see differences of opinions. So, students tend to think that their teacher might think less of them when they did not do well on the task as reflected in the kind of feedback that they receive (Bedford & Legg, 2007).

Teacher-feedback ideas are usually delivered using longer explanations and with less praise (Cho & MacArthur, 2010; Cho et al., 2006; Gielen et al., 2010a; Tsivitanidou et al., 2011). Teacher's explanations during feedback can increase students' belief in the feedback because it allows for elaboration of the ideas (Rich et al., 2017). The explanations can also support students to recognize important aspects of a concept (Corral & Carpenter, 2020) and increase the engagement with it (Rich et al., 2017), thereby promoting better retention, understanding and transfer/application of the concept (Butler et al., 2013; and Rich et al., 2017). Transfer of learning according to Barnett and Ceci (2002) involves two sequential

cognitive processes: (1) retention and then (2) understanding. These two cognitive processes are further broken down into three steps. The first two require retention: (a) recognizing the relevance of acquired knowledge, and (b) recalling the knowledge. The last step (c) applying the knowledge to a new context requires understanding. Because explanations promote both retention and understanding, it can potentially support transfer of learning.

Whole-class discussion provides an opportunity for teachers to explain feedback ideas. It is during the whole-class discussion that the teacher can provide explanations to the canonical ideas to the whole class. During whole-class discussion, the teacher is likely to direct students' attention towards the essential ideas that students might have overlooked during their in-group discussions (Becker et al., 2015). The IRF sequence, i.e., Initiation-Response-Follow-up or Feedback (Sinclair & Coulthard, 1975) has been identified to be a pervasive structure of whole-class interaction between the teacher and students in Singapore (Chin, 2006). The IRF involves three discursive moves: Initiation (the teacher asks a question), response (students answer) and follow-up or feedback from the teacher. This feedback is typically a comment or a statement followed by another question or further statements that explain more conceptual ideas. As far as feeding-back of the IRF sequence is concerned, it can be considered as non-interactive/authoritative when a teacher comments on what is correct and what is not correct in students' work. This is because although students' ideas are considered, it is the teacher (being the more 'knowledgeable other') who works on synthesizing those ideas and uses them to suggest improvements (Mortimer and Scott, 2003). Notably, the teacher's feedback depends on how students respond to the initiation move and its quality can be affected by the teaching-learning time available (Chin, 2006), which in turn is impacted by the class size.

When the class size is large, there is limited time for the teacher to give regular and detailed feedback. As a result, teacher-feedback tends to become less frequent and

generalised, which potentially contributes to lower achievement gains particularly in the upper secondary grades (Roberts, 2007). The Philippines has larger and more crowded classes (~50 students) compared to other Asian countries, i.e., Malaysia is 34, Thailand is 42, Japan is 34 and India is 39 (Class Size and Conditions Act, 2022). Filipino students need help in obtaining feedback that is useful in supporting their classroom learning given the contextual constraints of a large number of students in a limited space where movement of teachers across groups/students is very limited. Previous studies have identified student-feedback as a useful strategy to give feedback in large classes (Rodríguez et al., 2022; Søndergaard & Thomas, 2004; Xu & Harfitt, 2019). Student-feedback has been identified valuable because it helps provide timely feedback, support fair feedback provision for each student (every student has the same opportunity to receive feedback), and facilitate student interaction (or discussion) that may lead to the creation of new understanding (Rodríguez et al., 2022; Søndergaard & Thomas, 2004; Xu & Harfitt, 2019). Hence, I wanted to try if student-feedback or peer-feedback can be considered as a potential substitute for teacher-feedback in large classes. On implementing feedback to support drawing to learn chemical reactions in large classes, I have found no previous studies that explored what feedback features are useful. Knowing these useful feedback features may help relieve the challenges in implementing feedback in large classes.

Peer-feedback. Student-feedback or peer-feedback is a process when students themselves, who are equal in one or more of the following aspects of age, education level or level of expertise provide and receive feedback from each other (Panadero et al., 2018). In other words, the students take both roles as assessees and assessors for each other, and benefit from both roles. Nevertheless, being an assessor who provides feedback tends to be more beneficial than being an assessee who receives feedback (Li et al., 2010). While an assessee simply receives insights from others to improve the work, an assessor can see the strengths

and weaknesses of others' work. The assessor can then develop a deeper understanding of the success criteria. Consequently, the assessor can evaluate and improve his/her work relative to his/her peers' work and the success criteria (Hill & Edwards, 2019; Tsivitanidou et al., 2011). This evaluation of one's work and identification of areas for improvement can encourage metacognitive awareness (Repice et al., 2016).

Peer-feedback has certain benefits due to the ideas coming from multiple sources (i.e., feedback from two or more student-peers). According to Cho and MacArthur (2010), it generates a rich resource of feedback, which can help detect more problems in student work. It also minimises the risk of incorrect feedback because students can check each other's insights. Additionally, it was identified to promote collective consensus of ideas. And because each student faces the same difficulties as other students, feedback from multiple peers can give more personally relevant comments using the same language and avoiding jargon. In improving writing quality, undergraduate students from a university in the USA who received feedback from multiple peers via a computer-based feedback system produced better drafts compared to those who received feedback from a single expert (Cho & Schunn, 2007). Also, those in the multiple feedback group received more total feedback of all types compared to the single expert group (Cho, Schunn, & Charney, 2006). Multiple peer-feedback also has affective benefits. It has been found to promote teamwork and is positively received by students (Bedford & Legg, 2007). It has also been found to yield greater psychological safety (i.e., a higher belief that the environment is safe from interpersonal risks) and lower value diversity (i.e., high agreement between the assessor and assessee about the quality of the assessee's task performance) (van Gennip et al., 2010).

Unlike the teacher who mainly uses explanations to deliver feedback, peers have been found usually to ask for more clarification and elaboration during feedback (Cho et al., 2008; Cho & MacArthur, 2010; Cho, Schunn, & Charney, 2006). Students' frequent use of

questions in their feedback is likely because they have a developing level of domain knowledge and need additional ideas to fill in the knowledge gaps. Nonetheless, students asking questions to each other can be beneficial because it can stimulate each other's thinking. Students can become involved in active knowledge construction wherein prior knowledge is used to create meanings for the incoming new information (Chin & Osborne, 2008). Concurrently, the prior knowledge is modified in the light of the new information (Chouinard, 2007). Simply put, posing questions leads to understanding facilitated by thinking (Alexander et al., 2022). So, peer-feedback, although it is different from teacher-feedback, can still be of high quality.

It is however acknowledged that peer-feedback can have drawbacks due to students being novice feedback providers with a developing level of domain knowledge. The feedback providers' domain knowledge can influence the features of feedback (Hovardas et al., 2014; Strijbos & Sluijsmans, 2010). Because students do not have the same broad and organised domain-specific knowledge that an expert possesses, the feedback may result in inaccurate or non-essential suggestions (Cho & MacArthur, 2010; Cho, Schunn, & Charney, 2006; Hovardas et al., 2014), or just focused on the surface features (rather than the deep structures) of the task (Chi & VanLehn, 2012). Peer-feedback can also be highly reliable (i.e., consistent feedback comments on the same task or output by the same assessor overtime) but moderately valid (i.e., feedback reflects the actual quality of the task or output) (Cho & MacArthur, 2010; Cho, Schunn, & Wilson, 2006) likely due to students possessing the same developing level of conceptual ideas and agreeing on the same novice ideas. Notably, reliability and validity tend to decrease if peer-feedback is used without support. In a study of peer assessment skills among seventh graders in Cyprus (Tsivitanidou et al., 2011), students were asked to assess each other's web portfolios without receiving training. Also, the assessment criteria were generated by the students themselves. The unmediated peer

assessment resulted in student-generated criteria that did not agree with experts' criteria and was not consistent even among themselves (Tsivitanidou et al., 2011). To help avoid this, a structure (i.e., criteria and predetermined scaffold prompts) can be provided to support the delivery of both peer-feedback and teacher-feedback.

Students can also have reservations about the feedback of their peers. Students are aware that in some instances it is difficult for their peers to give honest feedback (Killingback et al., 2020). Students may also doubt their peers' ability to give feedback on a challenging task where they themselves struggle, e.g., a task requiring deeper conceptual understanding. Students may have uncertainties if their peers correctly understood the assessment criteria (Hill & Edwards, 2019) or have the required level of conceptual understanding. In a study conducted in Belgium among Grade 7 students' writing quality, those who received a high quality of constructive feedback from highly competent peers did not improve the quality of their writing. The result of the study is attributed to the lack of acceptance and trust on peer competence (Gielen et al., 2010a). Nevertheless, the uncertainty about the peers' relative status as a feedback provider and reservations about the accuracy of peer-feedback can be valuable. It can induce students to study further the to-be-learned material. Students could elicit further discussion, check instructional resources, ask the teacher further questions and/or perform self-corrections. Doing these will promote 'mindful reception' and a deeper understanding of the to-be-learned material (Bangert-Drowns et al., 1991; Yang et al., 2006). The space and time created for the assesseees to think further about the feedback is also the attributed reason why peer-feedback did not work so much through specific suggestions for improvement (directive feedback); rather non-directive feedback was associated more with improved performance (Cho & MacArthur, 2010). Indeed, students need time to develop the capacity to monitor the quality of their work (Sadler, 2009). It is then possible that incubation

effects could occur. This is when improvement in learning occurs later after some delays.

Learning can then be assessed after a delayed period to account for incubation effects.

Small-group discussion provides an opportunity for students to deliver peer-feedback. It is during small-group discussion that in-depth discussion of the task or concept could occur among student-peers. For example, in the context of chemistry education, it was during small-group interaction that an in-depth discussion of symbolic representations (mathematical procedures, terminologies and symbolisms) occurred among undergraduate chemistry majors from a university in the USA (Becker et al., 2015). However, discourse patterns during small-group discussion among multiple student-peers (6-8 members with a peer leader) differ from the IRF sequence during whole-class discussion (Repice et al., 2016). Discourse pattern during small-group discussion involves True Dialogue (i.e., students pose questions not to assert the right answer but to work out the problem), Cross Discussion (i.e., a peer leader moderating conversation ensuring all members participate in the problem-solving process by building up from each other's ideas), and Group Work (i.e., the group works cooperatively and shares on the tasks) (Repice et al., 2016). Therefore, peer-feedback can be considered as interactive/dialogic where students take turns to listen, explore and work on each other's points of view (Mortimer and Scott, 2003).

Teacher-feedback and peer-feedback in science education. I have found that teacher-feedback (or expert-feedback) in science education studies has been delivered using different media: Whole-class discussion (Chin, 2006; Oh, 2005; Warfa et al., 2014) or one-to-one discussion with students (Chin, 2006; Warfa et al., 2014) through the teacher's discursive moves (face-to-face format); online environment (Cho & MacArthur, 2010); and writing, i.e., logs, tests and worksheets (Bedford & Legg, 2007; Coenders, 2016; Schneider et al., 2018). I also found that teacher-feedback has been investigated in different learning contexts: In-class presentation of science investigation (Oh, 2005); teacher questioning (Chin, 2006); testing

(Schneider et al., 2018); feedback preference (Bedford & Legg, 2007; Coenders, 2016); and writing quality (Cho & MacArthur, 2010), but not in drawing chemical reactions at the submicroscopic level.

One study was found that examined how teacher-feedback impacted students' submicroscopic understanding. The case study of Warfa et al., (2014) in the USA investigated how the teacher's discursive moves impacted general chemistry students' submicroscopic understanding of the dissolution of ionic and molecular compounds in water. Students' submicroscopic understanding was assessed through their dialogues. The study found out that on the one hand, teacher's discursive moves (i.e., communicative, confirming, reorienting, and linking moves) during dialogic discourse (teacher-student interaction during small-group discussion) positively impacted submicroscopic understanding. On the other hand, the teacher's discursive moves (i.e., generative, instructional, and sharing moves) during monologic discourse (whole-class discussion) was found to have no impact on submicroscopic understanding. Although students generated particulate drawings, those were not evaluated. The particulate drawings were only used as a secondary reference for triangulation. Furthermore, the teacher's dialogues were not analysed for their *feedback foci* (e.g., visual-spatial elements of the drawings, verbal linkages with the drawings, triplet relationship or prerequisite chemistry knowledge). In chemistry education, the teacher plays a critical role in supporting students to learn using representation, particularly if it is the first-time students are encountering them. This is because students experience a degree of cognitive overload when interpreting individual representations or when making links between several representations (Ferreira & Lawrie, 2019). An example is the task of integrating the chemistry triplet: macroscopic, submicroscopic, and symbolic, which remains a struggle for students (Taber, 2018a). Learning chemical reactions across the chemistry

triplet contributes to better conceptual understanding of it (Hilton & Nichols, 2011; Yeşiloğlu, 2019).

Peer-feedback in science education has been found to be delivered using small group discussion through a peer leader (face-to-face format) (Repice et al., 2016), which is a medium distinct from teacher-feedback. Nonetheless, peer-feedback just like teacher-feedback has also been delivered via an online environment (Chang & Chang, 2013; Cho & MacArthur, 2010; Tsivitanidou et al., 2011) and written worksheets (Bedford & Legg, 2007). Peer-feedback just like teacher-feedback was also investigated in the learning contexts of writing quality (Cho & MacArthur, 2010) and feedback preference (Bedford & Legg, 2007). However, there are other learning contexts where peer-feedback has been investigated differently from teacher-feedback: Students' talk (Repice et al., 2016) and students' peer assessment skills (Tsivitanidou et al., 2011).

One study was found that investigated peer-feedback in the context of drawing to cultivate submicroscopic understanding. The intervention study of Chang and Chang (2013) explored how peer-feedback influenced Taiwanese Grade 8 students' submicroscopic understanding of a chemical reaction (i.e., combustion of hydrogen). Working in dyads, the students were asked to observe a dynamic computer model of the combustion of hydrogen. Using computer drawing, students created molecular models (diagrams) of the combustion of hydrogen. Then, using online scaffolds made up of three explicit criteria (model accuracy, model purpose, and model constituents) and 29 premade comments (each criterion was made up of six to fourteen premade comments), students critiqued three molecular diagrams: scientific model, peer's model, and fictitious peer's model. Students provided feedback by selecting from the premade comments. The feedback provided on the molecular diagrams was analysed based on the percentage of the students' comments that concurred with the teacher's comments; the percentage of the students' comments that reflected or did not reflect

the quality of the model being critiqued; and level of collaborative discussion (i.e., how many of the comments were discussed collaboratively). After critiquing, students revised their own molecular models.

Results from the study of Chang and Chang (2013) showed that the online scaffolds helped students provide comments on the molecular models that were valid (i.e., consistent with the teacher) and highly correlated with the quality of the model being critiqued. However, this study of Chang and Chang (2013) looked at peer-feedback on drawings of a reaction viewed simply as spatial rearrangement (molecular models), which is less complex than a reaction that involved particle identity transformation (e.g., atoms and/or molecules becoming ions). Hence, different *foci* of peer-feedback (i.e., visual-spatial elements of the drawing, verbal linkages to the drawing, triplet relationship and prerequisite chemistry knowledge) may be useful. Also, peer-feedback *moves* (e.g., adding, removing, revising, posing questions, identifying, explaining, and affirming ideas) were not examined. Moreover, peer-feedback in the study of Chang and Chang (2013) was delivered virtually and not face to face. In Section 2.2.2, face-to-face feedback is described as personalised, dynamic, genuine, and generates high-quality interactions. And students have been found to highly value face-to-face feedback because of the presence of human connection (Killingback et al., 2020). Lastly, in the study of Chang and Chang (2013), peer-feedback on the drawings was provided by only two student-peers. Having more than two assessors could provide more variety of feedback ideas that could help detect more problems in the work (Cho & MacArthur, 2010). I have not found studies that explored how face-to-face multiple peer-feedback influenced freehand drawing to represent chemical reactions.

In sum, teacher-feedback and peer-feedback are both useful sources of feedback. Each has distinct characteristics that determine its benefits as well as its drawbacks. Table 3 presents a summary of the characteristics, benefits, and drawbacks of the two feedback

sources that have been identified from the literature. As noted earlier, these previous studies were predominantly done in the context of writing to learn. And I have found no studies that investigated the impact of these characteristics on freehand drawing to represent chemical reactions at the submicroscopic level. It is envisaged that these reported characteristics can be extended to drawing chemical reactions. The next section describes the ICAP theory, which is a framework used to describe students' engagement with learning activities. It is proposed that the ICAP framework can be used to describe how teacher-feedback and peer-feedback interact with drawing to represent chemical reactions.

Table 3 *Summary of Characteristics, Benefits and Drawbacks of Teacher-Feedback and Peer-Feedback*

Teacher-feedback
Characteristics
Teacher acts as assessor and students act as assesseees
One-way channel of assessment
Benefits
Considered as one of the most powerful formative assessment tools to support classroom learning
Teacher is an expert who can provide accurate feedback, with more ideas, and longer explanations
Teacher's marking skills cannot easily be equalled
Students tend to give weight to teacher's viewpoint because authority and expertise are recognised
Students tend to act on teacher-feedback because time spent for giving feedback is considered well-invested
Whole-class discussion provides opportunity for the teacher to model canonical understanding and direct students' attention to important ideas overlooked during small in-group discussion

Teacher's discursive moves (i.e., communicative, confirming, reorienting, and linking) during dialogic discourse (teacher-student interaction during small-group discussion) positively impacted submicroscopic understanding

Drawbacks

Associated with poorer performance in writing, i.e., led to simple revisions with no improvement in text complexity

The teacher usually has knowledge unavailable to students. Also, the teacher tends to use jargon that students rarely understand

The teacher may underestimate the difficulty level of a task for the students

Associated with high-value diversity and low psychological safety. Can also lower students' sense of self-corrections

Students believe that the teacher might think less of them for not doing well on the task as reflected in the feedback

Peer-feedback

Characteristics

Students act both as assessors and assessees for each other

Reciprocal channel of assessment

Benefits

Students take the benefits of both assessor and assessee roles

Offers a rich resource of feedback to detect more problems about the task

Promotes opportunities for students to achieve collective consensus and check on each other to minimise incorrect ideas

Can give more personally relevant feedback because students face the same difficulties and speak the same level of language while avoiding jargon

Fosters teamwork, greater psychological safety, and lower value diversity. Positively received by students

Small-group discussion provides opportunity for students to engage in an in-depth discussion of ideas

Associated with improved writing performance. Non-directive feedback creates time and space for students to reflect on what they are trying to achieve in their writing, which can lead to better revisions

Drawbacks

Might not work so much through specific suggestions for improvement (directive feedback)

Students lack the domain knowledge to detect the deep structures of a task. Instead, students tend to focus on the non-essential aspects

Can be highly reliable but moderately valid because students are novices. Also, reliability and validity tend to decrease if used without support

Lack of acceptance and trust on peer's competence (i.e., in assessing the work and understanding the assessment criteria)

Students need longer time to develop the capacity to monitor the quality of their work

2.2.4 What is the ICAP Theory?

The ICAP theory of active learning (Chi, 2021, 2009; Chi & Wylie, 2014) was developed as a conceptual framework for describing students' cognitive engagement with instruction and instructional materials. Based on this theory, there is a greater probability that students' overt behaviours are approximations of their cognitive engagement. The ICAP theory (Chi, 2021, 2009; Chi & Wylie, 2014) describes four modes of cognitive engagement. These four modes are (1) *Interactive*, (2) *Constructive*, (3) *Active* and (4) *Passive*. The following is the description of each mode (Chi & Wylie, 2014): *Passive* involves receiving and focusing on the information without doing anything else observable and related to the learning task. It is however possible for a student to appear *passive* but covertly processing the task deeply. *Active* involves motoric action or physical manipulation with focused attention (not mindlessly) on the learning task (p. 222). There are however instances where it is difficult to recognise if a student is focusing while still being *active*. *Constructive* involves generating or producing outputs or products beyond what was originally available. Lastly,

Interactive involves students working together under two conditions: (a) their dialogues are in the *Constructive* mode and (b) that there is a sufficient degree of turn-taking.

Chi (2021), and Chi and Wylie (2014) hypothesise that each ICAP mode is associated with a specific knowledge-change process (i.e., dynamic process students engage in when learning new information) and expected cognitive outcome. Chi (2021), and Chi and Wylie (2014) further posited that these knowledge-change processes and expected cognitive outcomes are transferable to any instructional activities that belong to the same mode. The *Passive* mode involves the storage of the new information in an encapsulated or isolated way as the knowledge-change process. The resulting cognitive outcome is that students can recall the information. The *Active* mode involves integrating incoming information into the stored prior knowledge. As a result, the existing schema becomes ‘complete, coherent, salient and strengthened’ (p.228). Students can then apply the knowledge to a similar (not identical) context. The *Constructive* mode involves inferring new knowledge from the integrated schema. Consequently, the existing schema becomes enriched, elaborated and can be linked to other schemas. For example, knowledge of a concept can be used to understand and explain new concepts (there is transfer). *Constructive* differs from *Active* because *Constructive* involves the generation of new information other than what is presented in the presented instructional material whereas *Active* involves manipulation of just the presented information. Finally, the *Interactive* mode involves inferring new knowledge from each other (e.g., peers). At the start of the interaction, this new knowledge was unknown to either peer. Subsequently, new products, interpretations, procedures and ideas are co-created.

With feedback as the context of instruction, the ICAP theory may be used as a framework to characterise students’ cognitive engagement with the two common feedback sources. For teacher-feedback where the teacher is often the prime source of feedback, the students’ cognitive engagement with the feedback can be described as *Active* (not *Passive*).

Teacher-feedback on students' submicroscopic drawings of reactions delivered during whole-class discussion (where students present their drawings to the class) involves the teacher suggesting improvements synthesised from the students' existing ideas. Because students revise their drawings after receiving the feedback, it is likely that students are not passively receiving the feedback ideas but covertly processing them. These feedback ideas from the teacher are then integrated into the students' existing ideas to support them in improving their drawings. For peer-feedback, students' cognitive engagement can be characterized as *Interactive*. The two conditions of the *Interactive* mode are satisfied during peer-feedback: (1) Students' dialogues are about making improvements in the revised drawings, which is a *constructive* task; and (2) during small-group discussion, students take turns in their roles as assessors and assessees for each other's drawings. Notably, I have not found studies that utilised the ICAP as a framework to characterise students' cognitive engagement during teacher-feedback and peer-feedback on drawing to represent chemical reactions.

The ICAP framework further hypothesizes that learning decreases in this direction: $I > C > A > P$ (Chi 2021, 2009; Chi & Wylie, 2014). Superior learning is to be expected when students are engaged at the *Interactive* mode than at the *Constructive* mode (Wiggins et al., 2017). Consequently, *Constructive* mode is associated with better learning than *Active* mode, which in turn is better than *Passive* mode. *Interactive* subsumes *Constructive*, which subsumes *Active* and consequently *Passive*. The ICAP theory posited that both *Passive* and *Active* do not foster support in seeing deep structures of a problem or concept while *Constructive* and *Interactive* foster deep learning (Chi & VanLehn, 2012). Deep structures refer to the interactions between the surface details (details that can easily be perceived) of the problem or concept (Chi & VanLehn, 2012).

There are however studies that criticize the central assumption of the ICAP on the order of engagement modes and direction of learning. Thurn et al., (2023) argued that one engagement mode is not always superior to another. The effectiveness of an engagement mode depends on proper timing and students' readiness. So, even a lower engagement mode can result in superior learning than a higher engagement mode 'when used in the right way, on the right learners and with the right timing' (p. 1). For example, it is a well-established learning principle that novice learners benefit from a more teacher-directed instruction (akin to the passive or active mode, which ICAP considered as inferior engagement modes) particularly when the learning task is conceptually-challenging (Thurn et al., 2023). In Chemistry learning, El-Mansy et al., (2022) stated higher cognitive engagement is not always desirable. In their study, El-Mansy et al., (2022) found that students' inability to use a model of thermal energy and calorimetry scientifically (perhaps due to their lack of conceptual understanding) led them to engage *interactively*; however, it did not help them obtain the scientific answers. Moreover, different learning activities that belong to the same engagement mode were found to not affect learning in the same way. Wekerle et al., (2024) found that three different *passive* activities had different effects on students' perception of how much they learned and their situational interest during the lesson. Students viewed peer presentations to have contributed more to their learning and situational interest, than listening to their teachers and plenary discussion. It was argued that the ICAP modes are too coarse-grained to capture the effects of different instructional activities on student learning (Wekerle et al., 2024).

2.3 Research Questions

The literature review identified feedback as a valuable support for drawing to learn chemical reactions at the submicroscopic level (see Section 2.1.3). Feedback on drawing reactions can impact not only the quality of students' drawings but also their mental models

of the reactions. The two sources of feedback (teacher-feedback and peer-feedback) commonly used to support classroom learning possess distinct characteristics that offer certain benefits and drawbacks. My research study sought to find out: *How may the source of feedback affect students' drawings of chemical reactions at the submicroscopic level?* To answer this, three specific research questions were identified. The first question examined: *Is there a difference in the order of difficulty in drawing chemical reactions?* It is worthwhile to answer the first question to describe the complexity of drawing different reaction types and how it varies with the feedback source. The second question asked: *Is there a difference between the quality of students' drawings in the teacher-feedback group and peer-feedback group?* Answering the second question is valuable to find out in what ways the two feedback sources were effective when used to support drawing to learn different reaction types. And the third question explored: *What are the features of feedback that are valuable for supporting drawing to learn chemical reactions?* Answering the last question provides insights into and behind the conditions for the effectiveness of the two feedback sources.

Chapter 3 Methodology

This chapter begins by presenting the research paradigm that guided the research design. Then, the context of the study – the Philippine secondary science curriculum and the participants, data collection materials and procedure, and data analysis techniques are discussed. The discussion of how data were analysed follows the sequence of the research questions. Towards the end of the chapter, a summary of the data collection tools, the kind of data collected, and how data were analysed to address each of the research questions are reviewed.

3.1 Research Paradigm

This research study was informed by the post-positivist paradigm. Ontologically, the post-positivist paradigm assumes that a social phenomenon is objective and external to the researcher (acts as an observer). A certain level of objectivity and fairness can be utilised to approximate (probability) the truth of the social phenomenon (Lin, 2015; Mack, 2010); compared to the positivist paradigm that assumes absolute objectivity to grasp the truth of the social phenomenon with absolute certainty (Mack, 2010). Epistemologically, the post positivist paradigm views a social phenomenon as constituting of variables that act on one another. Hence, the scientific method, i.e., experiments can be employed to study how these variables of the social phenomenon interact (Lin, 2015; Mack, 2010). In this study, the social phenomenon is the use of drawing and feedback as a teaching-learning strategy for chemical reactions. The implementation of drawing and feedback as a teaching-learning strategy is composed of interacting variables that can be controlled, observed, and assessed.

3.2 Research Design

This research study used a quasi-experimental two-group design. The purpose of this quasi-experimental two-group design was to see how two treatments (i.e., teacher-feedback and peer-feedback) that were both considered effective compared with each other (Taber,

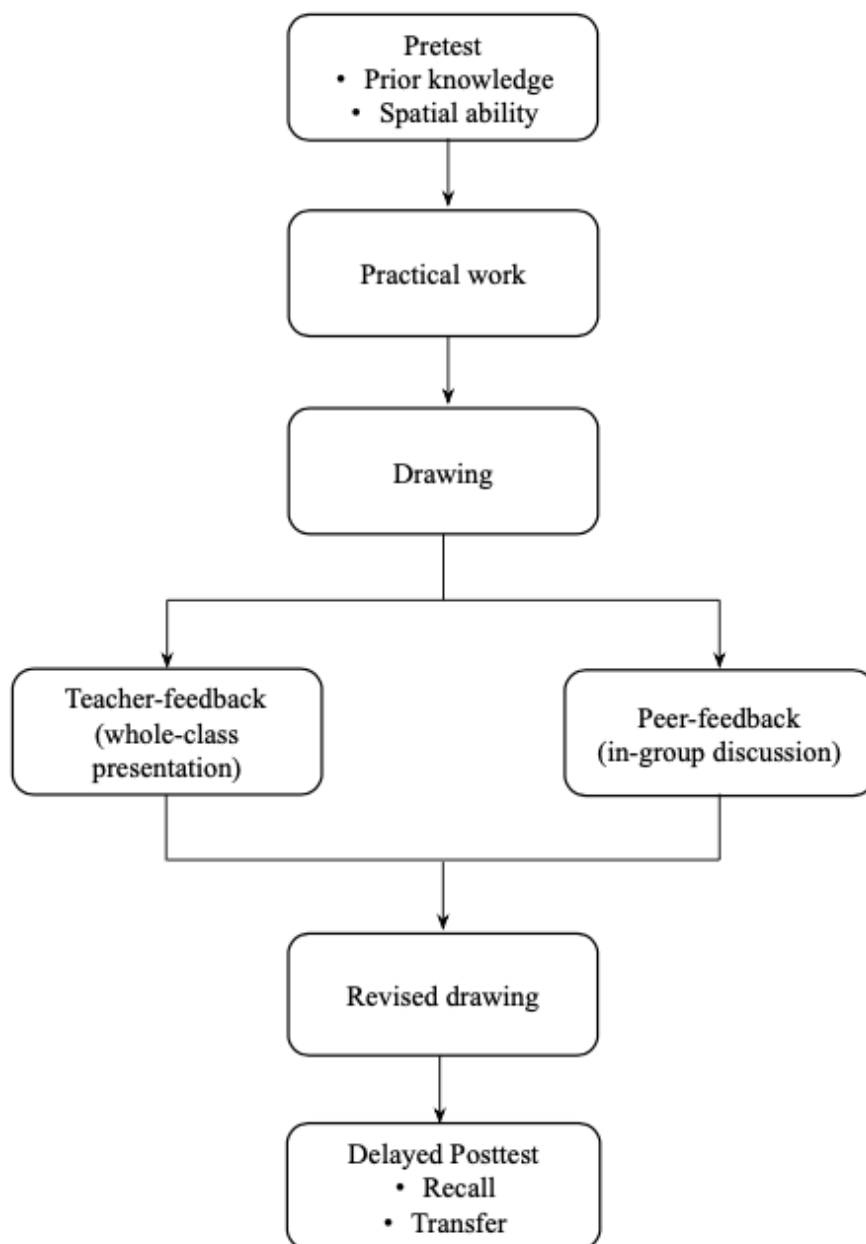
2019a). As a method of collecting data, quasi-experiments are more likely to emulate real-world conditions, unlike true experiments where there is great control over conditions and participants (Brown & Harris, 2018). Quasi-experiments have currently been identified as one of the least represented methods for feedback research within *in vivo* classrooms (Brown & Harris, 2018).

The main research question that this study intended to answer was: *How may the sources of feedback affect students' drawings of chemical reactions at the submicroscopic level?* Figure 5 presents the flowchart on how the study answered the research question through the intervention. Two Grade 11 classes (the school system of the Philippines is discussed in the next section) were randomly assigned into either of the teacher-feedback group or peer-feedback group. Both teacher-feedback and peer-feedback are considered powerful sources of external support for classroom learning as identified in the literature review. Students from both groups were given the pre-tests on prior knowledge and spatial ability, which were identified as control variables that influence drawing. Then, practical work on the four types of chemical reactions, namely: combination/synthesis, decomposition, single displacement, and double displacement were performed. After which, students drew what they thought had happened at the submicroscopic level for the observed chemical reaction.

After drawing, students from one class received feedback from the teacher while the other received feedback from their peers. In the teacher-feedback group, students presented their drawings to the whole class and received feedback from the teacher. In the peer-feedback group, students presented their drawings within their teams and received feedback from each other. After receiving feedback, students from both groups revised their drawings. Students' learning was assessed in terms of recall and transfer. Post-tests a month after (delayed post-tests) the teaching-learning intervention were administered. The quality of

drawings between the teacher-feedback and peer-feedback groups were assessed and compared by scoring the visual elements and their spatial relationships. Feedback generated by the two groups was analysed for their *foci* and *moves* (Section 3.6). The features of feedback were used to make sense of the quality of drawings.

Figure 5 *Flowchart of the Study*



The next section covers the context of the study, which includes an overview of the Philippine secondary science curriculum, and the description of the research participants. The rationale of why the study was conducted with them is explained in this section.

3.3 Context of the Study

3.3.1 Overview of Science Curriculum in Philippine Secondary Schools

The Philippines adopted the K to 12 Basic Education Curriculum, which covers Kindergarten and 12 years of basic education (six years of elementary school, four years of junior high school and two years of senior high school). Kindergarten is mandatory for five-year old children and is a prerequisite for admission to elementary school. At the Kindergarten students learn the alphabet, numbers, shapes, and colours through games, songs, and dances in their mother tongue. Elementary school is from Grade 1 to 6. Elementary school students learn mathematics, science, social science, Philippine history and culture, physical education, arts, their mother tongue, Filipino and English. From Grade 4 to 6, Filipino and English are used as language of instruction. Junior high school is from Grade 7 to 10 and senior high school is from Grade 11 to 12. At the senior high school students can choose to take one out of four paths namely: Academic, arts and design, sports, and technical-vocational. Each path has its strands, e.g., Science, Technology, Engineering, and Mathematics (STEM) strand is part of the academic path.

Science is taught, beginning at Grade 3 through high school with English as the language of instruction. From elementary school to junior high school, there are four areas for science: matter; living things and their environment; force, motion, and energy; and earth and space. All these four areas are taught in each grade level (Grade 3 to 10). At the elementary school, these four areas are taught at the same times of the school year (there are four terms each school year). At the junior high school, these four areas are taught at different times of

the school year. Table 4 presents the distribution and sequence of the four science areas from Grade 3 to 10.

Table 4 *The Distribution and Sequence of the Four Science Areas from Grade 3 to Grade 10*

Term	Elementary School					Junior High School		
	G3	G4	G5	G6	G7	G8	G9	G10
1 st	Matter	Matter	Matter	Matter	Matter	Force, Motion, and Energy	Living Things	Earth and Space
2 nd	Living Things	Living Things	Living Things	Living Things	Living Things	Earth and Space	Matter	Force, Motion, and Energy
3 rd	Force, Motion, and Energy	Force, Motion, and Energy	Force, Motion, and Energy	Force, Motion, and Energy	Force, Motion, and Energy	Matter	Earth and Space	Living Things
4 th	Earth and Space	Earth and Space	Earth and Space	Earth and Space	Earth and Space	Living Things	Force, Motion, and Energy	Matter

The science concepts for each area from Grade 3 to 10 are taught in spiral progression, i.e., from simplest to the more complicated, as students advance through grade levels. For example, at the junior high school in the area of matter: Grade 7 students learn about how to conduct a scientific investigation and classification of matter; Grade 8 students learn about particulate nature of matter, atomic structure, and the periodic table; Grade 9 students learn about the electronic structure of matter, chemical bonding, carbon compounds and mole concept; and Grade 10 students learn about gas laws, biomolecules, and chemical reactions. [The specific content topics, subtopics, and learning competencies for each content topic can be found on the curriculum guide for science at the junior high school (DepEd, 2016a)]. At the junior high school, chemical reactions include concepts on mass

conservation, factors affecting the rate of chemical reactions and how these factors are applied in various processes, i.e., food preservation, materials production, control of fire, pollution, and corrosion (DepEd, 2016a).

At the senior high school, the school year is divided into two semesters. Grade 11 STEM students are required to take General Chemistry 1 and 2 during the first and second semesters respectively. The first semester is from August to December while the second semester is from January to June. General Chemistry 1 covers topics on matter and its properties; measurements used in chemistry; atoms, molecules, and ions; mole concepts; chemical reactions and stoichiometry; gases; electronic structure of atoms; periodicity; chemical bonding; and organic compounds. General Chemistry 2 covers topics on intermolecular forces; physical properties of solutions; thermochemistry; chemical kinetics; chemical thermodynamics; chemical equilibrium; acid-base equilibria and salt equilibria; and electrochemistry. [The specific content topics, subtopics, and learning competencies for each content topic can also be found in the curriculum guide for General Chemistry 1 and 2 (DepEd, 2016b)]. The topic on chemical reactions for General Chemistry 1 includes concepts on writing chemical equation, balancing chemical equations, Law of Conservation of Mass, pieces of evidence of chemical reaction, mass relationships in chemical reactions and types of chemical reactions. The types of chemical reactions are about the four types based on how atoms rearrange, i.e., combination, decomposition, single displacement and double displacement (DepEd, 2016b).

3.3.2 Participants

The participants of the study were two Grade 11 General Chemistry 1 classes in a public laboratory senior high school in the Philippines during the school year August to December 2018. It is called a laboratory high school because it is affiliated with the College of Education of a public university where teacher education students conduct their practice

teaching. Both the laboratory high school and the university are government funded. The laboratory high school follows the curriculum set by the Philippine Department of Education (DepEd, 2016b). Students were typically 17 years old. There were 50 students and 51 students in the teacher-feedback group and peer-feedback group respectively

The task of drawing chemical reactions at the submicroscopic level is cognitively demanding and require students with knowledge of an array of prerequisite and interconnected chemistry ideas, e.g., distinction between atoms, molecules and ions; identity of polyatomic ions; assignment of oxidation numbers; recognising chemical symbols; naming and writing chemical formulae; Law of Conservation of Mass; balancing chemical equations; distinction between ionic, covalent and metallic compounds; and particle nature of matter, among others. These prerequisite and interconnected chemistry ideas were part of the Grade 11 General Chemistry 1 curriculum. Hence, Grade 11 General Chemistry students were chosen to implement drawing of chemical reactions. Also, these Grade 11 students of General Chemistry were assumed to have exhibited aptitude towards science because of their admission to the STEM track. Compared to junior high school students, these Grade 11 students are assumed to be better equipped at implementing drawing of chemical reactions.

Participation in the study was voluntary. Ethical approval was sought from The University of Hong Kong before data collection (see Appendix I.1 The University of Hong Kong Ethics Approval). Participants including the teacher (male), the students, and the school principal were requested to provide their consent. Since the student-participants were minors, parental consent was also secured. Data collection was completed while the researcher was at The University of Hong Kong. When the researcher transferred to The University of Waikato, the Faculty of Education Research Ethics Committee reviewed and ratified the ethical approval from The University of Hong Kong (see Appendix I.2 The University of Waikato Ethics Approval). The next section presents the materials that were used in this

study and how data were collected. I also present the different threats to the validity of a quasi-experimental study and how these threats were addressed in this study.

3.4 Data Collection Materials and Procedure

3.4.1 Pre-test and Practice Lessons

Before the intervention and data collection, permissions to conduct the study were sought from the school principal of the laboratory high school and from the Dean of the College of Education of the university. After permissions were given, the intervention and the data collection commenced. A coin toss was done to randomly assign the two Grade 11 classes into the two treatment group conditions, i.e., teacher-feedback and peer-feedback. Then, the spatial ability test (see Appendix A) and prior knowledge test (see Appendices B.1, B.2 and B.3) were administered.

Prior knowledge and spatial ability were identified as control variables that affect drawing (see Sections 2.1.3 and 2.1.4 in the literature review), therefore their influence on drawing was removed in the subsequent statistical analysis. In terms of spatial ability, the Paper-Folding Test VZ-2 (Thurstone, 1962) was used. The internal consistency (estimate of how well the test items measure the same construct or concept) of the Paper Folding Test was determined by the researcher. In terms of prior knowledge, I constructed a 40-item multiple-choice to assess students' prerequisite ideas about the description of a chemical reaction; reactivity series of metals; writing chemical equations; formation of chemical bonds and compounds; identifying metals and nonmetals; identifying elements and compounds; and the differences between ions, atoms, and molecules (Appendix B.1). Expert validity of the prior knowledge test was established by the chemistry educator who was the lead curriculum designer for science in the Philippine K to 12 curriculum. A Table of Specifications (see Appendix B.3) was constructed to map out the distribution of the test items across the learning competencies pertinent to chemical reactions. These learning competencies were

from junior high school science (DepEd, 2016a) and senior high school General Chemistry 1 (DepEd, 2016b). Two other learning competencies were also added: (1) using the idea of the reactivity series to explain displacement reaction and predict its product; and (2) recognising the four types of chemical reaction. For each learning competency, the test items were distributed across three levels of cognitive domains, i.e., knowing, applying, and reasoning based on the TIMSS 2015 Science Framework (Jones et al., 2015). These cognitive domains describe the thinking process students were expected to demonstrate while answering the test item.

To control for novelty effect (i.e., the tendency of students to improve their performance because of the increased interest in the newly introduced teaching-learning strategy) and reactivity effect (i.e., the tendency of students to improve their performance because they are aware that they are being observed due to the presence of the researcher, and the video- and audio-recorders) (Taber, 2019a), four practise lessons were conducted before the intervention. These lessons covered single displacement and decomposition reactions (see Table 5).

Table 5 *Chemical Reactions Studied During the Practice Lessons*

Practice lesson	Chemical reaction	Chemical equation
1-2	Extraction of iron	$2\text{Fe}_2\text{O}_{3(s)} + 3\text{C}_{(s)} \rightarrow 4\text{Fe}_{(s)} + 3\text{CO}_{2(g)}$
3-4	Dissociation of ethanoic acid in water	$\text{CH}_3\text{COOH}_{(aq)} + \text{H}_2\text{O}_{(l)} \rightarrow \text{CH}_3\text{COO}^{-}_{(aq)} + \text{H}_3\text{O}^{+}_{(aq)}$

The goal of the practice lessons was to familiarise the teacher and students with the teaching-learning intervention. Four worksheets (i.e., two chemical reactions $\times$ two feedback conditions) (see Appendices C.1 and C.2) were developed by the researcher and used during the practice lessons. The implementation of these practice lessons is presented in Section 3.5.

3.4.2 Intervention

The intervention was made up of eight lessons (60-90 minutes each lesson). Two consecutive lessons covered each of the four types of chemical reactions: combination/synthesis, decomposition, single displacement, and double displacement. Table 6 lists the chemical reactions that students explored in the class. In each lesson, students generated submicroscopic drawings of the chemical reaction.

Table 6 *Chemical Reactions Studied During the Lessons for the Intervention*

Worksheet	Chemical reaction	Chemical equation
1	Burning of magnesium	$2\text{Mg}_{(s)} + \text{O}_{2(g)} \rightarrow 2\text{MgO}_{(s)}$
2	Decomposition of hydrogen peroxide	$2\text{H}_2\text{O}_{2(aq)} \xrightarrow{\text{MnO}_2} 2\text{H}_2\text{O}_{(l)} + \text{O}_{2(g)}$
3	Reaction between magnesium and copper (II) chloride	$\text{Mg}_{(s)} + \text{CuCl}_{2(aq)} \rightarrow \text{Cu}_{(s)} + \text{MgCl}_{2(aq)}$
4	Reaction between sodium sulfide and hydrochloric acid	$\text{Na}_2\text{S}_{(s)} + 2\text{HCl}_{(aq)} \rightarrow \text{H}_2\text{S}_{(g)} + 2\text{NaCl}_{(aq)}$

During the intervention, students from both groups received a worksheet (see Appendices D.1 to D.4) for each reaction type. Eight worksheets (i.e., four reaction types $\times$ two feedback conditions) were developed by the researcher. Overall, the practice lessons and lessons in the intervention covered six chemical reactions (see Tables 5 and 6). Internal consistency of the worksheets was calculated for all six chemical reactions (Practice lessons and intervention). Moreover, the worksheets were used to:

- present to students the instruction for the practical work on the types of chemical reactions
- record students' macroscopic observations
- present the symbolic representation (i.e., chemical equation of the chemical reactions)

- give the predefined instructions (i.e., drawing of the chemical species before and after the reactions)
- provide the working space for students' drawings of their submicroscopic ideas (both for the initial and revised versions)
- present the feedback criteria and prompts to both the teacher and the students' peers as shown in Tables 7 and 8, respectively

Table 7 *Criteria for Evaluating Drawings*

Criteria	Description		
	The drawing's representation of the criterion is...		
	Excellent	Good	Poor
1. Identity of the chemical species involved in the reaction (e.g., atoms, ions, or molecules)			
2. Conservation of particles before and after the chemical reaction based on the balanced chemical equation	clear, accurate and complete	not so clear, have minor errors and some details are missing	difficult to understand, have major errors and many important details are missing
3. Arrangement of the chemical species			
4. Distance between particles of the chemical species based on their phases			

Table 8 *Prompts for Delivering Feedback*

Moves	Prompts
Adding a detail	I think you need to add because This is based on.....
Removing an idea	I think you need to remove..... because..... This is based on.....
Revising an idea	I think you need to revise..... because..... This is based on.....
Finding out more about an idea	I think you might want to explain more about.....because..... This is based on

The feedback criteria presented in Table 7 identified the aspects of drawing chemical reactions on which feedback was focused. Generating drawings with features that accurately reflect the conceptual ideas has been found to predict better submicroscopic understanding (Stieff & DeSutter, 2021). In drawing chemical reactions, conceptual ideas were found to be represented only as visual elements (Kern et al., 2010; Nyachwaya, 2016) but not the spatial relationships among them. Also, features of dynamic processes such as electron transfer were also found to be rarely represented by students during freehand drawing (Bongers et al., 2019). To support students to generate drawings that reflect submicroscopic understanding, both assessors (i.e., teacher and student-peers) were asked to evaluate the drawings based on these four criteria in Table 7. These criteria are tied to the essential conceptual ideas about chemical reactions. These criteria incorporated both the visual and spatial elements of the drawing including changes on them to show the associated dynamic processes, i.e., identity transformation and particle rearrangement.

The *feedback moves* identified how the feedback was delivered following the prompts presented in Table 8. Research has identified that predefined instructions are critical to providing support, which is essential for student-generated drawing (Van Meter & Garner, 2005) and feedback (Tsivitanidou et al., 2011) to be effective.

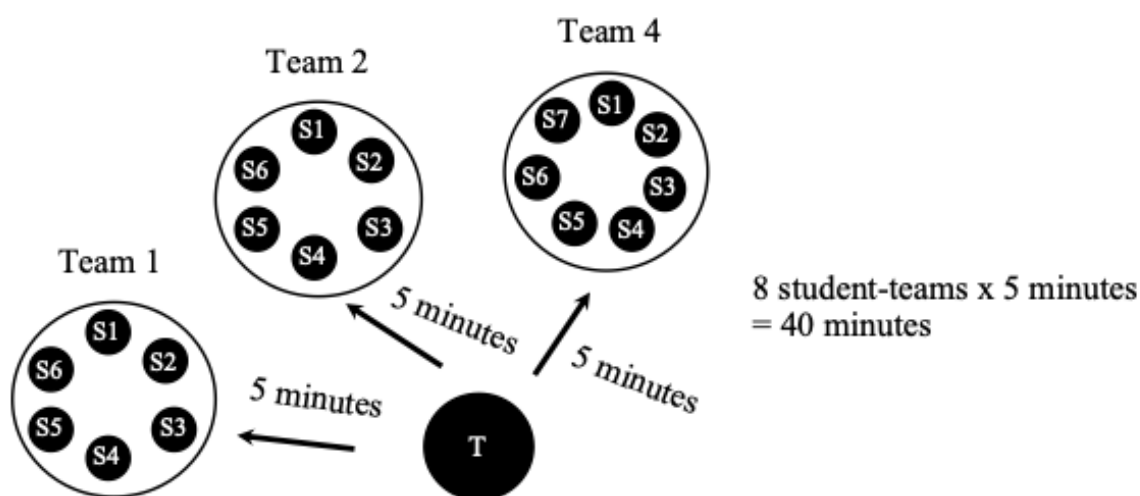
During the intervention, students from both the teacher-feedback and peer-feedback groups formed a team of six or seven members. Eight teams were formed. All the teams were heterogeneous based on their prior knowledge test scores and gender (see Table 9). For the prior knowledge test, students' scores were divided into upper half and lower half by locating the median. Students as a team conducted practical work about the types of chemical reactions. On the worksheet, each student individually listed their macroscopic observations and drew their submicroscopic ideas about those macroscopic observations (with annotations) guided by the symbolic representation (i.e., chemical equations).

Table 9 *Composition of Student Teams in the Teacher-Feedback and Peer-Feedback Groups Based on Prior Knowledge and Gender*

Team	Number of students per team		Prior knowledge		Gender	
	Teacher-feedback (N = 50)	Peer-feedback (N = 51)	Teacher-feedback	Peer-feedback	Teacher-feedback	Peer-feedback
1	6	6	2 upper half; 4 lower half	2 upper half; 4 lower half	3 males; 3 females	3 males; 3 females
2	6	6	2 upper half; 4 lower half	2 upper half; 4 lower half	3 males; 3 females	3 males; 3 females
3	6	7	2 upper half; 4 lower half	3 upper half; 4 lower half	3 males; 3 females	3 males; 4 females
4	7	7	3 upper half; 4 lower half	3 upper half; 4 lower half	3 males; 4 females	3 males; 4 females
5	7	7	4 upper half; 3 lower half	4 upper half; 3 lower half	4 males; 3 females	4 males; 3 females
6	6	6	4 upper half; 2 lower half	4 upper half; 2 lower half	3 males; 3 females	3 males; 3 females
7	6	6	4 upper half; 2 lower half	2 upper half; 4 lower half	3 males; 3 females	3 males; 3 females
8	6	6	3 upper half; 3 lower half	2 upper half; 4 lower half	3 males; 3 females	3 males; 3 females

In the teacher-feedback group, students were instructed that they were not to interact with their peers while drawing. This no peer interaction helped ensure that it was only the teacher who was the primary, if not the only, source of feedback. After drawing, students in each team chose one drawing that best represented their team's submicroscopic ideas. This drawing was then presented before the whole class. The whole class presentation was done by one to three representatives from each team. The teacher provided feedback using the criteria and prompts listed in Tables 7 and 8. The teacher spent 5 minutes to give feedback on the drawing of each team. Hence, the total time for the teacher to give feedback was 40 minutes. This is illustrated in Figure 6.

Figure 6 Total Time for the Teacher to Give Feedback or for All Eight Student-Teams to Receive Feedback



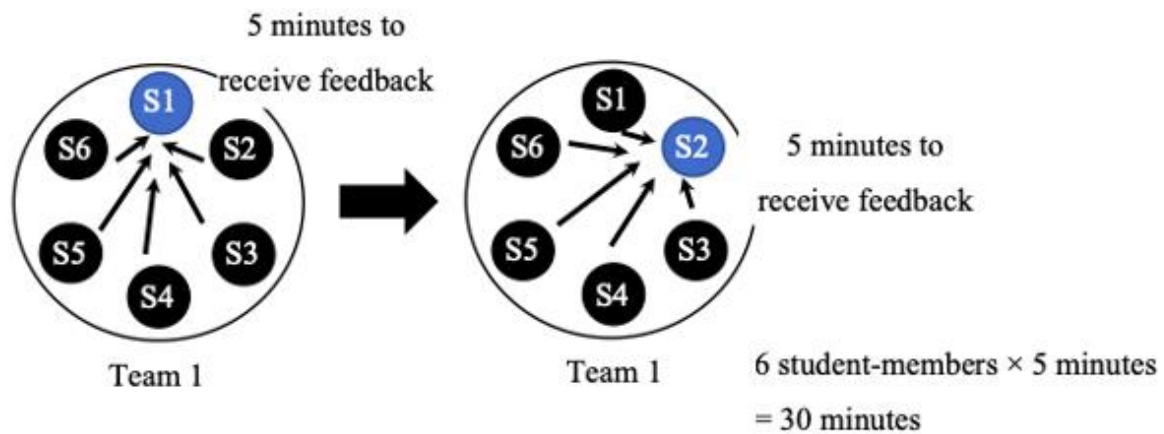
While the teacher was giving feedback, four video recorders and an audio recorder were placed around the classroom to capture:

- the students' presentation of drawings in front of the class together with the teacher giving feedback (two video recorders from two different angles and one audio recorder). The recorders were used to determine the *foci* and *moves* of the feedback given by the teacher.
- the general view of the class to see its overall atmosphere and interaction while the teacher was giving feedback (two video-recorders from two different angles).

In the peer-feedback group, students conducted the same tasks as the teacher-feedback group. However, instead of choosing one drawing for the whole class presentation, peer-feedback students presented in a round-robin way. Peer-feedback students presented their drawings to each other within their team and received feedback from each other using the same criteria for evaluating drawings and prompts for delivering feedback (see Tables 7 and 8). In each team, students took turns in their roles as an assessee and as an assessor. Each assessee was given 5 minutes to receive feedback from all their peers within their team.

Hence, for a team with six members (e.g., Team 1), it took a total of 30 minutes to finish giving and receiving feedback. This is illustrated in Figure 7.

Figure 7 Total Time for Peers to Give/Receive Feedback



In the peer-feedback group, four video recorders and one audio recorder were also placed around the classroom to capture:

- the interaction of the student team of interest during peer-feedback (two video recorders from two different angles and one audio recorder). Team 1 was chosen as the student-team of interest because it was the most stable, i.e., all student-members were always present in class and adhered conscientiously to the procedure. The recorders were used to identify the *foci* and *moves* of the feedback that students' peers provided.
- the general view of the class to see its overall atmosphere and interaction during peer-feedback (two video-recorders from two different angles).

After receiving feedback from either the teacher or peers, the students revised their drawings individually. In the teacher-feedback group, students were instructed to disband from their teams and not interact with their peers while drawing. In both groups, after revision, all worksheets were collected. After one month, students answered the recall test

(see Appendix E) and a transfer test (see Appendix F) individually. This was to assess the learning outcomes and to account for the delayed effects (Taber, 2019a) of the intervention. The delayed post-test was set for a month after the intervention because students studied other related concepts on chemical reactions within the one-month gap (lecture and laboratory). Such concepts include stoichiometric calculations related to chemical equations including gaseous reactions, limiting and excess reagents, and theoretical yield, actual yield, and percent yield calculations.

Both groups were taught by the same teacher. The teacher received the teacher's guide (see Appendix G) on how to implement drawing coupled with feedback as a teaching-learning strategy across the 12 lessons (four practice lessons and eight lessons for the intervention). The researcher developed the teacher's guide for the teacher to know the intervention process, overall objective of the teaching-learning strategy, and specific preparations and procedures including how the worksheets were used. Additionally, a classroom observation checklist (see Appendix H) was developed and used by the researcher to check on the possible bias from the teacher towards one group while implementing the intervention. Teacher fairness was evaluated by determining the frequency to which the teacher met six criteria (see Appendix H) across a scale (i.e., SD – strongly disagree, D – disagree, A – agree, and SA – strongly agree).

Lastly, as much as possible, the two groups were kept similar, these include:

- a. The time of teaching: as much as possible the two groups were taught either both in the morning or both in the afternoon with the same lesson on the same day. Teaching the two groups with the same lesson at the same time helped avoid treatment diffusion effects (i.e., occurs when treatment groups communicate with each other and learn from each other).

- b. The physical conditions of the classroom were also kept similar. Both classes had similar ventilation, lighting, seating arrangement and noise quality. For ethical considerations, after assessing recall and transfer achievements of both groups, the teacher-feedback group was exposed to the peer-feedback condition and vice versa. Students from both classes had the same lessons and were exposed to the same conceptual ideas about chemical reactions, yet there was a difference in the learning conditions. The first treatment group was assumed to have *actively* received feedback from a domain expert (teacher) while the other treatment group *interactively* received feedback from novices (students' peers). Experiencing one treatment and not the other treatment may have effects on the students. To minimise such effects, the treatments were reversed for both groups.

3.4.3 Recall and Transfer

The recall test assessed how well the students could recall the essential ideas about the four types of chemical reactions that they encountered during the intervention. The transfer tests were used to assess how well the students understood and could apply those essential ideas into new but related situations (Chi & VanLehn, 2012). Since the lessons were taught using drawing, it was assessed via drawing (Johnson & Reynolds, 2005). In the transfer tests, students were given a new set of chemical reactions that they had not encountered during the intervention but fell under each of the four types of chemical reactions that they studied. During the intervention, students used the essential ideas in drawing metallic (atoms); ionic (ions); and covalent (molecules) substances that exist in different phases: Solid (crystalline), liquid, aqueous and gas. The new set of chemical reactions in the transfer test were chosen to assess students' application of the same essential ideas except that the chemical reactions were new.

Expert validity for both recall and transfer tests were established by asking the chemistry educator who was the lead curriculum designer for science in the Philippine K to 12 curriculum to validate it. Scoring of the transfer test is discussed in Section 3.6.1. Table 10 presents the different chemical reactions in the transfer test one month after the intervention. The next section discusses how the practice lessons were implemented to introduce drawing of submicroscopic ideas and give feedback on drawing to students.

Table 10 *Chemical Reactions in the Transfer Test One Month After the Intervention*

Item	One month after the intervention	Type of reactions
1	$2A_2B(l) \rightarrow 2A_{2(g)} + B_{2(g)}$	Decomposition
2	$CaCl_{2(aq)} + 2KOH_{(aq)} \rightarrow Ca(OH)_{2(s)} + 2KCl_{(aq)}$	Double displacement
3	$2Be_{(s)} + O_{2(g)} \rightarrow 2BeO_{(s)}$	Combination/synthesis
4	$Ca_{(s)} + H_2SO_{4(aq)} \rightarrow CaSO_{4(aq)} + H_{2(g)}$	Single displacement

3.5 Practice on Drawing and Feedback

The first four lessons (first two topics) were the practice lessons. These practice lessons were used to demonstrate how drawing was done and to simulate and practice what (*foci*) and how (*moves*) feedback was given by both the teacher and peers. The way these four lessons were delivered, i.e., how drawing was done and how feedback was provided, were identical to the eight lessons during the intervention.

The teacher's guide (see Appendix G) was received by the teacher before the first practice lesson. The teacher studied it and then met with the researcher to discuss the purpose of the intervention, materials that were used and how the lessons were implemented in both the teacher-feedback and peer-feedback groups.

3.5.1 Practice Drawing of Submicroscopic Ideas

The two topics for the four practice lessons were: (1) Extraction of iron using carbon (lessons 1 and 2); and (2) dissociation of ethanoic acid in water (lessons 3 and 4) (see Table

5). The practice lessons were the same for both groups. In these lessons, students were introduced to the drawing of chemical species that exist in different states (solid, liquid, gas, and aqueous solution) during a chemical reaction. The extraction of iron using carbon was used because it is a common example of a reaction involving metal extraction from ores that has important industrial chemical applications. Iron extracted through this process is a widely used metal. It is acknowledged that drawing iron (III) oxide may be challenging for the students. This is why the particulate diagram of iron (III) oxide was provided to them as a guide (students did not draw them). The extraction of iron using carbon (lessons 1 and 2) provided the students the opportunity to see a representation of an ionic solid (as in iron oxide) and an amorphous solid (as in carbon) [the reactants], and to draw a metallic solid (as in iron) and molecular gas (as in carbon dioxide) [the products].

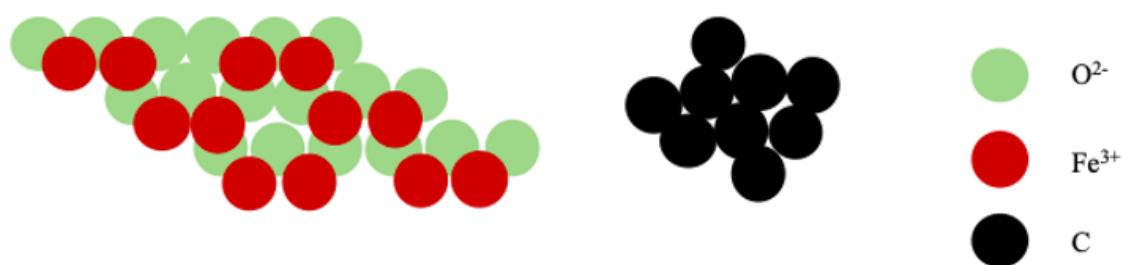
Before the practice lessons, the researcher talked to the students from each of the two groups about the purpose of the intervention. The researcher gave the students an overview of what they were expected to do for the next 12 lessons, i.e., to perform practical work on chemical reactions, implement drawing of submicroscopic entities, and receive feedback from the teacher (teacher-feedback group), or give and receive feedback from peers (peer-feedback group). For both groups, the first practice lesson started with the teacher presenting to the class the objective, materials, safety precautions, and the procedure of the practical work on extracting iron using carbon. Then the students, while working as a team, performed the practical work. Students were given the worksheet where all their macroscopic observations were recorded including their answers to the guide questions. After all the students finished the practical work, the teacher showed the word equation, chemical (symbolic) equation (see Figure 8), and particulate diagram of the chemical reaction (see Figure 9) via a PowerPoint presentation.

Figure 8 *Word and Chemical Equations for the Extraction of Iron Using Carbon*

Word equation: Solid iron (III) oxide reacted with solid carbon forming solid iron and carbon dioxide gas.

Chemical equation: $2\text{Fe}_2\text{O}_{3(s)} + 3\text{C}_{(s)} \rightarrow 4\text{Fe}_{(s)} + 3\text{CO}_{2(g)}$

Figure 9 *Particulate Diagram Used to Represent Solid Ionic Iron (III) Oxide Crystal and Solid Carbon at the Submicroscopic Level*



The teacher told the students that the particulate diagram (see Figure 9) represents the reactants of the chemical reaction that they had observed. The red circles represented iron (III) or Fe^{3+} ions bonded with the green circles, which represented oxide or O^{2-} ions forming iron (III) oxide. The black circles represented the carbon atoms. Students were also told that the iron (III) oxide is a solid ionic crystal where the ions are held by ionic bonding while carbon is an amorphous solid where the atoms are held by covalent bonds. Showing the equations followed by the particulate diagram helped introduce students to how drawing at the submicroscopic level was done and how it linked to symbolic representation.

Subsequently, using the equation (Figure 8) and the drawing of the reactants (Figure 9) as guides, students were asked to predict the products of the chemical reaction. They were asked to draw the products on the worksheets using their pens, pencils and/or colouring materials. Students were instructed to:

- add complete and detailed annotations like legends, labels, and charges on their drawings
- be specific when referring to ‘particles’, that is, to specify if they were referring to atoms, ions, or molecules
- write a detailed description of their drawings
- use different colours when drawing the same element to denote identity transformation, i.e., atoms to ions (or vice versa) after the chemical reaction

In both groups, the first lesson ended with the collection of the worksheets.

3.5.2 Practice Providing Feedback on Drawings

In the second lesson, the teacher showed a PowerPoint presentation of the feedback criteria and the prompts (Tables 7 and 8). These same criteria and prompts were also written on the students’ worksheets. The teacher used the particulate diagram of iron (III) oxide and carbon (see Figure 9) to illustrate each criterion (see Table 7). For example, to illustrate the identity criterion the teacher noted that the particles of iron (III) oxide were accurately shown as Fe^{3+} and O^{2-} ions (with correct charges) and that carbon is made up of atoms (with no charges). To illustrate the conservation criterion the teacher specified that students should count the number of atoms (or ions) in the two sides of the equation and make sure that they were the same based on the Law of Mass Conservation. To illustrate the arrangement criterion the teacher stated the iron (III) oxide was an ionic crystalline solid and therefore was accurately drawn as ions arranged in a regular and repetitive pattern (octahedral interstices), and carbon, being an amorphous solid, was accurately drawn as atoms arranged randomly. To illustrate the distance criterion, the teacher noted that both iron (III) oxide and carbon were accurately shown as solids made up of closely packed particles. Students were encouraged to ask questions on these criteria. To help students understand the feedback prompts (see Table 8), the teacher explained that the prompts were guides on how to deliver the feedback. For

example, if the drawing lacked two atoms on the product side, the student could be asked to draw two additional atoms ('adding a detail' move) to comply with the Law of Mass Conservation. The teacher emphasised that the feedback was aimed at improving the drawings.

After the teacher had explained the feedback criteria and prompts in the teacher-feedback group each team's representatives were asked to present before the whole class their drawing and the written description of the chemical reaction. The representatives explained why they drew the way they did. Then, the teacher began providing feedback on the drawings. While giving feedback, the teacher explicitly referred to the list of criteria and prompts to show to the students how the feedback was following that list. The teacher asked questions when he used the 'finding out more ideas' move (e.g., What kind of compound is carbon dioxide? Is it ionic or covalent? What happened to the Fe^{3+} and O^{2-} ions and the carbon atoms in the product?) students tried to answer those questions and further explain their reasoning. The teacher made follow-up comments or statements in the form of another question (e.g., *What happened to the ions? Did they change into another chemical species, or did they remain ions after the reaction?*) or further explanation of the conceptual ideas (e.g., *Covalent bond is to carbon and oxygen together. Bonded carbon and oxygen are now single molecules*). The teacher-student dialogue continued until all eight groups had received their feedback (see Figure 6). After which, students were disbanded from their teams and revised their drawings individually.

In the peer-feedback group after the teacher had explained the feedback criteria and prompts (see Tables 7 and 8), students were encouraged to ask questions, particularly on the use of technical or scientific terms in the criteria. Then, students gave feedback in a round-robin way (see Figure 7): Each student took turns in their roles as an assessee and as an assessor. A student in each team presented his/her drawing to the team by explaining and

justifying why he/she drew the way he/she did. After the presentation the other students, one after the other, provided feedback on the presented drawing using the criteria and the prompts. When the assessors gave feedback, the assessee answered and explained further. This exchange between students was particularly evident when the peer assessors used the ‘finding out more ideas’ *move*. When everybody had finished giving feedback, the next student began explaining his/her drawing. The cycle continued until everyone in the team had presented his/her work and had received feedback from his/her peers. While students were giving/receiving feedback, the teacher and the researcher moved around the class, observing each team to see whether the procedure was being followed and they listened to the team’s conversation. Particular attention was given to the feedback being provided, i.e., to ascertain whether it was accurately based on the criteria and if it was delivered following the prompts. If there were instances that this was not the case, the teacher or the researcher asked questions or offered explanations to the team to direct them to the correct understanding and application of the criteria and prompts. After all the students in the team received feedback, they revised their drawings. In both the teacher-feedback and peer-feedback groups, the second lesson ended with the collection of the worksheets.

This same procedure for the topic on the extraction of iron using carbon was followed for the other topics. The topic for the third and fourth lessons was the dissociation of ethanoic acid. This topic on the dissociation of ethanoic acid demonstrated to students how drawing was done when the chemical species involved in the chemical reaction are in the liquid phase and/or aqueous solution phase. Figure 10 represents aqueous ethanoic acid and liquid water at the submicroscopic level.

Figure 10 *Particulate Diagram Used to Represent Aqueous Ethanoic Acid and Liquid Water at the Submicroscopic Level*



(Upon further review, it was recognised that there were errors in the diagram, i.e., representing hydrogen and oxygen as ions. Nevertheless, the teacher correctly identified water as a molecule in his feedback)

3.6 Data Analysis Tools and Techniques

The discussion of how collected data was analysed followed the sequence of the research questions.

3.6.1 Research Questions 1 and 2

The first research question was: *Is there a difference in the order of difficulty in drawing chemical reactions?* And the second research question asked: *Is there a difference between the quality of students' drawings in the teacher-feedback group and peer-feedback group?*

To determine the quality of students' drawings of different reaction types, I assigned scores to the drawings based on the presence of the visual elements and their spatial relationships as representations of conceptual ideas. Such provision for a quantitative analysis provided a measure of overall achievement of students in their drawing. In this intervention study where I compared the effect of peer-feedback and teacher-feedback on student drawings, a comparison of overall achievement of the two groups revealed the effects of the intervention.

To determine if there were statistically significant differences between the quality of students' drawings of the different reaction types in the two groups during the intervention and one month after it, the drawings were first scored. Scoring rubrics (see Appendices J.1 to

J.3) were developed by the researcher to assess students' drawings. Students' drawings were scored in terms of their (a) visual elements and the (b) spatial relationships between them. There were two features for the visual elements: (1) identity of the particles of the chemical species, and (2) conservation of particles. For (b) spatial relationships, two features were also examined: (1) arrangement of particles and (2) distance between particles according to their respective phases. A detailed discussion of these visual and spatial elements of the drawing is found in Section 2.1.7 of the literature review.

The literature has identified a checklist (Leopold & Leutner, 2011; Leopold et al., 2013) or a rubric (general or specific, and/or holistic or analytical) as tools used to analyse drawings. Between a checklist and a rubric, I viewed a rubric as a more useful tool for analysing submicroscopic drawings of chemical reactions. In the rubrics, the descriptions on the quality of drawings were based on the visual and spatial features of the actual drawings (~2,200) that students generated in the intervention.

The Development of Scoring Rubrics for Student Drawings. In designing the rubrics drawings with similar visual and spatial features for each chemical species involved in the reaction were first sorted together. Then, these visual and spatial features were 'chunked' (Johnstone, 1997; Stieff et al., 2020; Taber, 2013), sequenced, set as descriptions of the quality of drawings, and assigned a score depending on how they reflected the accurate conceptual ideas. The combustion of magnesium is used as an illustrative example to demonstrate how scoring was done. The combustion of magnesium producing magnesium oxide involved three chemical species: solid magnesium metal, oxygen gas, and solid magnesium oxide. Table 11 shows the scoring for the identity of the particles. To assess the representation of identity transformation (or non-transformation) in the rubric conceptual ideas were sequenced between drawing a particle having a charge (most scientific) to no charge (unscientific) or vice versa depending on the correct identity of the particle.

The full scores were not the same for the three chemical species involved in the combustion of magnesium. Drawing molecules or ions were more complex than drawing atoms because they required the application of more conceptual ideas. Drawing molecules required not only knowing that they do not have charges but also recognising the correct ratios of the atoms in the molecule. Drawing ions required not only recognising that they were formed but also identifying their correct magnitudes and charges (+ or –). For example, drawing the identity of the particles of magnesium oxide was more complex than magnesium metal.

Table 11 *Scoring the Identity of the Chemical Species Involved in the Combustion of Magnesium*

Score	0	1	2	3
Solid magnesium metal	ion	atom		
Diatomic oxygen gas	discrete ions	diatomic ion	discrete atoms	diatomic molecule
Solid ionic magnesium oxide	Mg and O atoms	Mg ⁺ and O ⁺ ions	Mg ⁺ and O ⁺ ions	Mg ²⁺ and O ²⁻ ions

For magnesium metal, drawing it made up of atoms received a full mark (1 point) while drawing it as an ion had no mark (0 point). No matter what charge was assigned to magnesium metal it received no mark because it is made up of atoms (no charges) and not ions. For oxygen gas drawing it as a diatomic molecule (pair of bonded circles) with no charge was the most scientific and it received the full mark (3 points). Drawing oxygen gas as a discrete particle with a charge was not scientific (0 point) because oxygen was represented as discrete ions. Drawing oxygen gas as a discrete atom (discrete circle) received one mark deduction from the full score (2 points) because albeit oxygen was represented with no

charge it was not drawn as a molecule. And drawing oxygen gas as a diatomic ion (pair of bonded circles with charge) received one mark (1 point) because it represented oxygen as a 'molecule' (pair of circles), yet a charge was also assigned (unscientific). For magnesium oxide, drawing it as Mg^{2+} and O^{2-} was the most scientific (3 points) because particles were represented as ions with the correct magnitude and charges. Drawing magnesium oxide as Mg and O with no charges was unscientific (0 point) because magnesium oxide was represented as atoms. Drawing magnesium oxide as Mg^+ ion and O^- represented it as ions with the correct charges but incorrect magnitudes therefore one mark was deducted from the full score (2 points). Drawing magnesium oxide as Mg^- ion and O^+ ion represented them as ions but with incorrect charges and magnitude hence two marks were deducted from the full score (1 point).

Table 12 presents how scoring was done for the conservation of particles. Drawing both magnesium and oxygen with equal number of particles at the reactant and product sides based on the balanced chemical equation received the full mark (2 points). The Law of Conservation of Mass was represented for both magnesium and oxygen. Drawing both magnesium and oxygen with unequal number of particles at the reactant and product sides received no mark (0 point). The Law of Conservation of Mass was not represented for both magnesium and oxygen. Drawing either magnesium or oxygen with equal number of particles at the reactant and product sides represented that the Law of Conservation of Mass was represented only for one of the two chemical species; hence, a mark was deducted from the full score (1 point).

Table 12 *Scoring the Conservation of Particles Involved in the Combustion of Magnesium*

Score	0	1	2
$2\text{Mg}_{(\text{s})} + \text{O}_{2(\text{g})} \rightarrow 2\text{MgO}_{(\text{s})}$	The numbers of Mg and O particles before the reaction are not equal to the numbers of Mg and O particles after the reaction based on the balanced chemical equation	The number of Mg (or O) particles before the reaction is equal to the number of Mg (or O) particles after the reaction based on the balanced chemical equation	The numbers of Mg and O particles before the reaction are equal to the numbers of Mg and O particles after the reaction based on the balanced chemical equation

Table 13 shows how the arrangement of particles was scored. For solid magnesium, drawing it as particles arranged stacked above each other in a regular pattern received the full mark (2 points) because it represented magnesium as a metallic crystal. Drawing magnesium as scattered particles was unscientific (0 point) because it represented magnesium as an aqueous solution or as a fluid. Drawing magnesium as particles stacked above each other randomly represented that it was a metal but not crystalline hence one mark was deducted from the full score (1 point). For oxygen, drawing it as particles scattered randomly received the full mark (2 points) because that represented oxygen as a fluid. Drawing oxygen as not scattered particles received no mark (0 point) because that represented oxygen as a crystal. Drawing oxygen as particles scattered regularly partially represented that it was a fluid. However, particles of fluid have random not regular motion hence one mark was deducted from the full score (1 point). For magnesium oxide drawing alternating Mg and O particles in a regular pattern received the full mark (3 points) because it represented that magnesium oxide was an ionic crystal made up of bonded oppositely charged ions. Drawing scattered Mg and O particles received no mark (0 points) because it represented that magnesium oxide was a fluid. Drawing alternating Mg and O particles in a random pattern represented the bonding between the oppositely charged ions but only partly represented magnesium oxide as a

crystal; hence, a mark was deducted from the full score (2 points). And drawing alternating columns or rows of Mg and O particles represented magnesium oxide as a crystal but did not represent the bonding between the oppositely charged ions, i.e., particles with the same charges were bonded together in a column or row (1 point was given).

Table 13 *Scoring the Arrangement of Particles Involved in the Combustion of Magnesium*

Score	0	1	2	3
Solid magnesium metal	scattered	stacked above each other randomly	stacked above each other in a regular pattern	
Diatomic oxygen gas	not scattered	regularly scattered	randomly scattered	
Solid ionic magnesium oxide	scattered Mg and O particles	alternating columns or rows of Mg and O particles	alternating Mg and O particles in a random pattern	alternating Mg and O particles in a regular pattern

Table 14 presents the scoring for the distance between particles. For magnesium and magnesium oxide, drawing their particles as touching each other received the full mark (2 points) because it represented magnesium and magnesium oxide as solids. Drawing the particles with large empty spaces between them received no mark (0 point) because it represented magnesium and magnesium oxide as gases. One mark was deducted from the full score for drawing particles as close to each other but with little empty space (1 point) because this was an intermediate between accurately representing magnesium and magnesium oxides as solids and inaccurately representing them as liquids or gases. For oxygen, drawing the particles as having wide empty spaces between them received the full mark (2 points) because that represented oxygen as a gas. Drawing the particles as touching each other represented oxygen as a solid received no mark (0 point). Drawing the particles as having

empty spaces but not widely separated represented oxygen not completely as a gas but at least as a fluid hence a mark was deducted from the full score (1 point).

Table 14 *Scoring the Distance Between Particles Involved in the Combustion of Magnesium*

Score	0	1	2
Solid magnesium metal	having large empty spaces between particles	close to each other but with little empty spaces between particles	touching each other
Diatomic oxygen gas	touching each other	having empty spaces between particles but are not widely separated	having empty spaces between particles and are widely separated
Solid ionic magnesium oxide	having large empty spaces between particles	close to each other but with little empty spaces between particles	touching each other

Based on the same principles discussed above another set of rubrics was used to score the transfer test a month after the intervention (see Appendix K.2). The decomposition of hypothetical substance, A_2B is used to exemplify the scoring. Table 15 presents the scoring for the identity of the particles. For A_2B , drawing it as a cluster of three circles (made up of two A atoms and one B atom) received the full mark (3 points) because that represented A_2B as a molecule. Drawing A_2B as discrete circles of A and B ions received no mark (0 point) because that represented A_2B as made up of charged and discrete particles. Drawing A_2B as discrete circles of A and B received one mark deduction from the full score (2 points) because albeit A_2B was correctly represented with no charge it was not drawn as a molecule. And drawing A_2B as a polyatomic ion (cluster of two A and one B) represented A_2B as a charged particle but since it was shown as a ‘molecule’ (cluster of circles) it received a mark (1 point). Scoring the drawing of A_2 gas across the visual and spatial elements was like

scoring oxygen gas. The scoring for the drawing of oxygen gas has been discussed previously in scoring the drawings of the combustion of magnesium.

Table 15 *Scoring the Identity of the Chemical Species Involved in the Decomposition of Hypothetical A₂B*

Score	0	1	2	3
Liquid A ₂ B	discrete ions	polyatomic ion	discrete atoms	molecule
Diatomic A ₂ gas	discrete ions	diatomic ion	discrete atoms	diatomic molecule
Diatomic B ₂ gas	discrete ions	diatomic ion	discrete atoms	diatomic molecule

Table 16 presents the scoring for the conservation of particles. Drawing equal number of both A and B particles in the reactant and product sides based on the balanced chemical equation received the full mark (2 points). The Law of Conservation of Mass was reflected for both A and B. Drawing equal number of particles for either A or B received one mark deduction from the full score (1 point). Drawing an unequal number of both A and B particles received no mark (0 point); the Law of Conservation of Mass was not applied.

Table 16 *Scoring the Conservation of Particles Involved in the Decomposition of Hypothetical A₂B*

Score	0	1	2
$2A_2B_{(l)} \rightarrow 2A_{2(g)} + B_{2(g)}$	The numbers of A and B particles before the reaction are not equal to the numbers of A and B particles after the reaction based on the balanced chemical equation	The number of A (or B) particles before the reaction is equal to the number of A (or B) particles after the reaction based on the balanced chemical equation	The numbers of A and B particles before the reaction are equal to the numbers of A and B particles after the reaction based on the balanced chemical equation

Scoring the arrangement of particles is shown in Table 17. Drawing the particles of A_2B as randomly scattered received the full mark (2 points) because it represented A_2B as a fluid. Drawing A_2B as particles that were not scattered received no mark (0 point) because it represented water as ice. Drawing A_2B as particles scattered regularly partially represented that it was a fluid. Yet fluid particles have random motion hence, one mark was deducted from the full score (1 point).

Table 17 *Scoring the Arrangement of Particles Involved in the Decomposition of Hypothetical A_2B*

Score	0	1	2
Liquid A_2B	not scattered	regularly scattered	randomly scattered
Diatomic A_2 gas	not scattered	regularly scattered	randomly scattered
Diatomic B_2 gas	not scattered	regularly scattered	randomly scattered

Table 18 presents the scoring for the distance between particles. Drawing A_2B particles with little empty spaces between them received the full mark (3 points) because it represented A_2B as a liquid. Drawing A_2B particles as touching each other received no mark (0 point) because it represented A_2B as solid. Drawing A_2B particles with wide empty spaces between them but not as wide as the A_2 and B_2 gases represented A_2B as liquid, distinct from gas. But liquids do not have wide empty spaces, hence, one mark was deducted from the full score (2 points). Drawing A_2B particles as having wide empty spaces between them, comparable to the two gases may have represented A_2B as not solid, yet no distinction was made between liquid and gas. Consequently, two marks were deducted from the full score (1 point).

Table 18 *Scoring the Distance Between Particles Involved in the Decomposition of Hypothetical A₂B*

Score	0	1	2	3
Liquid A ₂ B	touching each other	having wide empty spaces between particles comparable to A ₂ and B ₂ gases	having wide empty spaces between particles but not as wide A ₂ and B ₂ gases	having little empty spaces between particles
Diatomic A ₂ gas	touching each other	having empty spaces between particles but are not widely separated	having empty spaces between particles and are widely separated	
Diatomic B ₂ gas	touching each other	having empty spaces between particles but are not widely separated	having empty spaces between particles and are widely separated	

Since each chemical reaction was constituted of a set of chemical species distinct from the other the full scores of the reactions are not the same. Double displacement reactions had higher full scores followed by single displacement, decomposition, and combination. Table 19 presents the full score for each chemical reaction in the revised drawings/recall test and transfer test.

Table 19 Full Scores for Each Chemical Reaction

Chemical reaction		Full score
<i>Revised drawing and recall test</i>		
$2\text{Mg}_{(s)} + \text{O}_{2(g)} \rightarrow 2\text{MgO}_{(s)}$	Combination	22
$2\text{H}_2\text{O}_{2(aq)} \xrightarrow{\text{MnO}_2} 2\text{H}_2\text{O}_{(l)} + \text{O}_{2(g)}$	Decomposition	27
$\text{Mg}_{(s)} + \text{CuCl}_{2(aq)} \rightarrow \text{Cu}_{(s)} + \text{MgCl}_{2(aq)}$	Single displacement	29
$\text{Na}_2\text{S}_{(s)} + 2\text{HCl}_{(aq)} \rightarrow \text{H}_2\text{S}_{(g)} + 2\text{NaCl}_{(aq)}$	Double displacement	36
<i>Transfer test</i>		
$2\text{A}_2\text{B}_{(l)} \rightarrow 2\text{A}_{2(g)} + \text{B}_{2(g)}$	Decomposition	25
$\text{CaCl}_{2(aq)} + 2\text{KOH}_{(aq)} \rightarrow \text{Ca}(\text{OH})_{2(s)} + 2\text{KCl}_{(aq)}$	Double displacement	42
$2\text{Be}_{(s)} + \text{O}_{2(g)} \rightarrow 2\text{BeO}_{(s)}$	Combination	22
$\text{Ca}_{(s)} + \text{H}_2\text{SO}_{4(aq)} \rightarrow \text{CaSO}_{4(aq)} + \text{H}_{2(g)}$	Single displacement	43

To determine if the two treatment groups had comparable prior knowledge and spatial ability, independent samples t-tests were done to compare their scores in the prior knowledge test and Paper Folding Test. In scoring the drawings the researcher and a science teacher who has a master's degree in chemistry, scored the drawings of 20% of the students (20 out of 101 students) during the intervention and from the recall and transfer tests one month after the intervention. Inter-rater reliability was established using intraclass correlation coefficient and differences in scoring were negotiated. After inter-rater reliability was established, the researcher scored the drawings of the remaining 80% of the students (81 out of 101 students).

Analysis of covariance (ANCOVA) was used to determine if there were statistically significant differences between the overall scores and scores for each type of chemical reaction of the two treatment groups during the intervention and one month after it while controlling for the effects of any covariate. Effect sizes (Cohen's *d* and partial Eta squared) were calculated to describe the magnitude of the differences between the two treatment groups. The overall scores showed the comparison of the overall quality of drawings of the two groups. The scores for each type of chemical reaction showed the comparison of the quality of drawings between the two groups for specific types of chemical reaction.

Repeated measure ANCOVA was also performed to determine if there were statistically significant differences in each treatment group's adjusted mean score percentages across the four types of chemical reactions. Repeated measure ANCOVA was used to compare how well each group drew the four types of chemical reactions, i.e., which type of chemical reaction was found by each group to be most (or least) challenging to draw.

3.6.2 Research Question 3

The third research question was: *What are the features of feedback that are valuable for supporting drawing to learn chemical reactions?*

To answer this question, I had to identify feedback episodes, code for feedback *foci* and *moves*, count the number of occurrences of each feedback *foci* and *moves*, and determine categories of *feedback foci*.

Identifying Feedback Episodes. The video recordings of the teacher and the students providing feedback were transcribed verbatim using the symbols adapted from Rodrigues (2018) (Table 20). An iterative cycle of deductive and inductive analysis was used to analyse the transcribed feedback dialogues. These feedback dialogues were segmented into feedback episodes. Episode boundaries were determined by shifts in the dialogue such as the provision of feedback on a new aspect of the drawing task. Here is an excerpt of feedback from the teacher on a drawing of the combustion of magnesium: *“Oxygen is correct. There are two - they are bonded together not like the other works - which are far apart. Although gas far apart.”* This excerpt contains two feedback episodes: (1) *“Oxygen is correct. There are two - they are bonded together not like the other works - which are far apart.”* (2) *“Although gas far apart.”* In the first episode, the teacher was affirming that the identity of oxygen was correctly drawn as a diatomic molecule, unlike the drawings from other teams where oxygen was represented as an atom, i.e., discrete circles which were far apart. In the second episode,

the teacher pinpointed that the distance between the oxygen particles was far apart because it was a gas.

Table 20 *Symbols for Transcription*

Symbol	Description
S	Student
T	Teacher
Ss	Students
—	A brief pause, less than a second
----	Pause, more than a second (note the time, e.g., ---- 3 secs.)
_____	Interruption. Cut off.
?	Rising intonation in talk, i.e., asking a question
*	Is incomprehensible
{ }	{laughs} or {shouts} or {non-English phrases}
...	A portion of the transcript was removed

Feedback Foci. Initially, each episode was deductively coded to characterise the *feedback foci* (aspects of the drawing task to which feedback was directed). The preliminary codes used for *feedback foci* were consistent with the scoring rubrics:

1. Visual elements
 - a. identity of the chemical species involved in the chemical reaction
 - b. conservation of particles
2. Spatial elements
 - a. arrangement of the particles
 - b. distance between particles

Apart from the (1) visual elements and (2) spatial elements as codes, there were feedback episodes focus on the drawing as a whole artefact and not on a specific visual or spatial element. Such *feedback focus* on drawing as a whole artefact was coded (3) ‘overall quality of the drawing’. For example, a peer gave this feedback on a student drawing of the reaction between magnesium and copper (II) chloride solution: “*It's good ---- (2secs) it's good – it's right – nothing's wrong with that (pointing at the whole drawing) _____ it's good.*”

There were *feedback foci* on aspects that were not directly about the drawing but were linked to it. Such *feedback foci* can potentially influence the quality of the drawings. These *feedback foci* did not fit the initial codes. New codes were inductively assigned to them. There were feedback episodes focus on the how the chemical equation of the reaction and macroscopic observations from the practical work relate to the drawings. For example, feedback on the ratio of the coefficients in the balanced chemical equation was linked to how conservation of particles (a visual element of the drawing) was represented in the drawing. *Feedback focus* on the chemical equation was coded (4) ‘linking symbolic representation’ and *feedback focus* on the macroscopic observations from the practical work was coded (5) ‘linking macroscopic observations’, based on the levels of the chemistry triplet. The drawing represented the submicroscopic level of the chemistry triplet because submicroscopic ideas were represented as visual and spatial elements of the drawing.

There were also feedback episodes that focused on the verbal elements of the drawing task. (6) ‘Written description of the drawing’ was used to code *feedback focus* on the explanation that students wrote about their drawings. (7) ‘Oral presentation’ was used to code the *feedback focus* on the students’ spoken explanation of their drawings during the whole-class presentation (teacher-feedback group) and in-group discussion (peer-feedback group). There was *feedback focus* on previously learned chemistry concepts. These previously learned chemistry concepts were not directly about the drawing but can potentially impact the quality of the drawing. For example, concepts about the difference between atoms, ions, and molecules; chemical behaviour of metals and nonmetals; and the octet rule can support the accurate representation of the identity of the chemical species involved in the chemical reaction (a visual element of the drawing). *Feedback focus* on these previously learned chemistry concepts was coded as (8) ‘prerequisite chemistry knowledge’. And there were feedback episodes that cannot be interpreted because they were either vague or incomplete

statements. Such feedback that could not be understood was coded (9) ‘cannot identify content’. An iterative process of repeated reading, coding of feedback episodes, and refining of codes was done using the four initial codes and the new codes as they emerged from the data. The process of assigning codes on the *feedback foci* aided the process of identifying the feedback episodes or setting the episode boundaries. Table 21 presents the list of these nine codes for *feedback foci*, their descriptions, and examples from both the teacher-feedback and peer-feedback groups.

Table 21 Codes for Feedback Foci, Their Descriptions, and Examples

Codes for <i>feedback foci</i>	Examples
1. Visual	
a. Identity of the chemical species Feedback on the representation of the identity of the particles of the chemical species (i.e., ions, atoms, or molecules) involved in the chemical reaction	<i>Teacher's feedback:</i> “In the reactant, magnesium and oxygen are in the form of atoms and molecules. But in the product, they are ions.” <i>Peer's feedback:</i> “Is that an atom?”
b. Conservation of particles Feedback on the representation of the Law of Conservation of Mass (or Particles)	<i>Teacher's feedback:</i> “The conservation of atoms is observed because no atoms are lost – no new atoms are added to the reaction.” <i>Peer's feedback:</i> “Six of this – six of this because this should be equal. This should be equal – all these here are equal.”
2. Spatial	
a. Arrangement of particles Feedback on the spatial distribution or arrangement of particles in specific phases	<i>Teacher's feedback:</i> “Mg should be pictured as surrounded by several O. Then, of course, that is for three-dimensional arrangement. And O is surrounded by Mg as well, in the crystal. So, you are to improve on that.” <i>Peer's feedback:</i> “Add more because you would not find only one (in solid phase) – you would not find

	only two moles of magnesium there. There are more.”
b. Distance between particles	<i>Teacher’s feedback:</i> “You can add more. You can add more – to make it – more compact – more, more particles there – show that it is compact (magnesium).”
Feedback on the spaces between particles in specific phases	<i>Peer’s feedback:</i> “This is solid, that is why this is compact.”
3. Overall quality of the drawing	<i>Teacher’s feedback:</i> “So here is the complete picture of the reaction.”
Feedback on the quality of the drawing as a whole	<i>Peer’s feedback:</i> “It's good ---- (2secs) it's good – it's right – nothing's wrong with that ____ it's good.”
4. Linking macroscopic observation	<i>Teacher’s feedback:</i> “Therefore, you need to include all the rest of the magnesium atoms in the strip to the illustration”
Feedback on the macroscopic events that were observed during the practical work and how it linked with the submicroscopic ideas in the drawing	<i>Peer’s feedback:</i> “What happened was when we lit the wooden splint, it started to burn because of the... Then there is the question, what happened to the wooden splint? So, the wooden splint burned and produced smoke because of *. It is because of the flame that the wooden splint was able to produce smoke. Here in question number 4, what is being asked is about the wooden splint.”
5. Linking symbolic representation (i.e., chemical equation)	<i>Teacher’s feedback:</i> “That number of atoms does not match the number of moles in the equation”
Feedback on the balanced chemical equation and if it concurred with the submicroscopic ideas in the drawing	<i>Peer’s feedback:</i> “Then you have to indicate that – it’s in aqueous solution or that it is <i>l</i> – just put it here at the side”
6. Written description of the drawing	<i>Teacher’s feedback:</i> “Just rephrase your general explanation for the reaction.”
Feedback on the written verbal description of the drawings	<i>Peers’ feedback:</i> “Then just put an explanation here - --- (3 secs) just that – that is the revision.”
7. Oral presentation	<i>Teacher’s feedback:</i> “Very well explained in some parts. Very good.”
Feedback on how the drawings were presented orally either	

during the whole-class presentation (teacher-feedback group) or during the in-group discussion (peer-feedback group).	<i>Peers' feedback:</i> There were no peer-feedback episodes classified under this <i>feedback focus</i> .
8. Prerequisite chemistry knowledge Feedback containing chemistry content from previous chemistry lessons	<i>Teacher's feedback:</i> "Example of electrolytes are? The acids – ... – ethanoic acid remember? Ethanoic acid yields H^+ – so it ionizes into H^+ and the $-CH_3COO^-$. And bases like magnesium hydroxide or strong bases like sodium hydroxide and salts like NaCl. NaCl when dissolved in water – NaCl is a soluble salt. All soluble salts – ionized completely in water." <i>Peer's feedback:</i> "Which one is smaller? Atom is smaller than a mole, right?"
9. Cannot identify content Feedback statements that were incomplete and lacked meaning hence were difficult to be understood	<i>Teacher's feedback:</i> "If you are adding more molecules of H_2O_2 ..." <i>Peers' feedback:</i> "That's what it is."

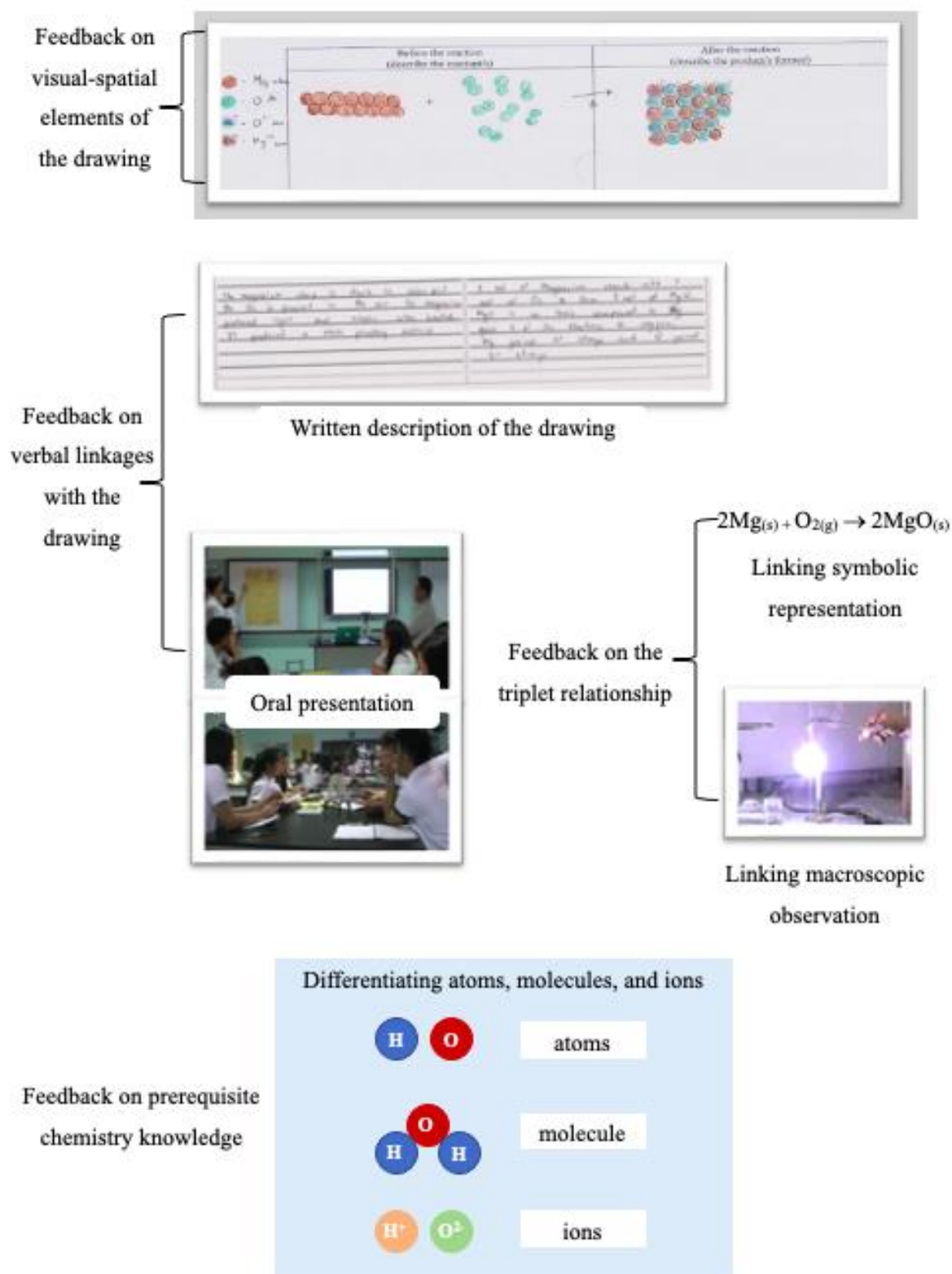
Categories of Feedback Foci. Codes for the nine *feedback foci* were categorised into four: (I) Feedback on visual-spatial elements of the drawing; (II) feedback on verbal linkages with the drawing; (III) feedback on the triplet relationship; and (IV) feedback on prerequisite chemistry knowledge. These four categories of *feedback foci* were based on the different aspects of the drawing task that were linked to the construction of a visual-spatial artefact of students' submicroscopic understanding of chemical reactions.

Feedback foci on the (1a) identity of the chemical species, (1b) conservation of particles, (2a) arrangement of particles, (2b) distance between particles, and (3) overall quality of the drawing was directly about the drawing per se, i.e., the submicroscopic ideas represented as visual and spatial elements of the drawing. Consequently, these five *feedback foci* were categorised as feedback on visual-spatial elements of the drawing.

Feedback foci on the (4) linking symbolic representation and (5) linking macroscopic observations contributed to the understanding of chemical reactions across the triplet relationship. The submicroscopic ideas represented as visual and spatial elements of the drawings were linked to the other two domains (i.e. macroscopic and symbolic) of the triplet relationship. These two *feedback foci* were categorised as feedback on the triplet relationship.

Feedback foci on the (6) written description of the drawing and (7) oral presentation were about the use of verbal modes of communication to complement the interpretation of the submicroscopic ideas that the students represented as visual and spatial elements of the drawings. These two *feedback foci* were categorised as feedback on verbal linkages with the drawing.

Feedback focus on (8) prerequisite chemistry knowledge was regarded as a category in itself. As a *feedback focus* category, feedback on prerequisite chemistry knowledge was linked to the other feedback categories and their *focus* types. For example, feedback on the previously learned concepts of the difference between atoms, molecules, and ions was linked to the ‘feedback on visual-spatial elements’ category specifically on the ‘identity of the chemical species’ *focus* type. These four feedback categories are illustrated in Figure 11.

Figure 11 *Categories of Feedback Foci*

Feedback Moves. Each feedback episode coded for its *focus* was also coded for *move* or how the assessor conveyed the feedback. Coding was initially done using the prompts suggested by Windschitl et al. (2018) which were: ‘adding an idea (or a detail)’, ‘removing an idea’/‘finding out more about the idea’, ‘revising an idea’, and ‘posing a new question’. However, ‘removing an idea’ and ‘finding out more about the idea’ were separated because when the assessor asked for further information about an aspect of the drawing, it did not mean that the aspect was to be removed. Then ‘finding out more about the idea’ was combined with ‘posing a new question’ because when an assessor posed a new question about a particular aspect of the drawing, the assessor was interested to find out more about that aspect. Consequently, feedback episodes were deductively coded based on *moves* using the following codes: (a) Adding a detail, (b) removing an idea, (c) revising an idea, and (d) finding out more about the idea.

During coding, there were *feedback moves* that did not fit the initial codes. Consider the feedback episode (verbatim statement) from a peer-assessor as an example: “*It's good ---- (2secs) it's good – it's right – nothing's wrong with that ____ it's good*”. In this feedback episode, the peer assessor was upholding the accuracy of the overall drawing to which his/her feedback was addressed. Consider another example. This feedback episode was from the teacher-assessor:

Most reactions take place in an aqueous or water solution. And when in water solution – when in water solution – substances like acids – bases and salts – all ionized in solution. Substances like acids – bases and salts – are ionized when in water solution.

In this feedback episode, the teacher was explaining about ionisation of acids, bases, and salts in an aqueous solution. Understanding the concept of ionisation of acids, bases and salts can potentially inform how the identity of chemical species can be represented

accurately in the drawing. These two feedback episodes did not fit the four initial codes. New codes were inductively determined and used. The feedback episode from the peer-assessor upholding the accuracy of the overall drawing was coded as ‘affirming an idea’. The feedback episode where the teacher explained about ionisation of acids, bases and salts in an aqueous solution was coded as ‘explaining an idea’. An iterative process of repeated reading, coding of feedback episodes, and refining of codes was done using the four initial codes and the new codes as they emerged from the data. Table 22 presents the list of these codes for *feedback moves*, their descriptions, and examples from both the teacher-feedback and peer-feedback groups.

Table 22 *Codes for Feedback Moves, Their Descriptions, and Examples*

Codes for <i>feedback moves</i>	Examples
1. Adding a detail The assessor (teacher or peer) was suggesting a detail to be incorporated	<i>Teacher’s feedback:</i> “You can add more. You can add more – to make it – more compact – more, more particles there – show that it is compact (Mg).” <i>Peer’s feedback:</i> “Add more because you would not find only one (in solid phase) – would not find only two moles of magnesium there. There are more.”
2. Removing an idea The assessor was suggesting dropping an idea	<i>Teacher’s feedback:</i> There were no teacher-feedback episodes classified under this <i>feedback move</i> . <i>Peer’s feedback:</i> “No. Remove this from the legend.”
3. Revising an idea The assessor was suggesting changing an idea. Revising an idea was used to code feedback episodes in which the <i>move</i> was neither adding a detail nor removing an idea.	<i>Teacher’s feedback:</i> “Since the magnesium in the reactant side – in the reactant is atoms. But on the – product side it is an ion. It is an ion so – kindly change colour as much as possible – so that you can distinguish atoms from ions.”

	<i>Peer's feedback:</i> "Six of this – six of this because this should be equal. This should be equal – all these here are equal. Change this."
4. Finding out more about the idea	<i>Teacher's feedback:</i> "What did you say about copper? Copper ---- (3secs) {where is that? or is it magnesium?} ---- (3secs)"
The assessor was interested to know more about an idea. The assessor posed a question	<i>Peer's feedback:</i> "What should be indicated?"
5. Affirming an idea	<i>Teacher's feedback:</i> "The conservation of atoms is observed because no atoms are lost – no new atoms are added to the reaction."
The assessor upheld the accuracy of an idea	<i>Peer's feedback:</i> "It's good ---- (2secs) it's good – it's right – nothing's wrong with that ____ it's good."
6. Identifying an idea	<i>Teacher's feedback:</i> "Take note that the colour changes."
The assessor pinpointed an idea but did not give any explanation to substantiate it	<i>Peer's feedback:</i> "Probably what we should do is to draw a strip made up of two long vertical columns with many atoms."
7. Explaining an idea	<i>Teacher's feedback:</i> "Most reactions take place in aqueous or water solution. And when in water solution – okay when in water solution – substances like acids – bases and salts – all ionized in solution. Okay – substances like acids – bases and salts – ionized when in water solution."
The assessor pinpointed an idea and then gave an explanation usually based on chemistry content to substantiate it	<i>Peer's feedback:</i> "What happened was when we lit the wooden splint, it started to burn because of the... Then there is the question, what happened to the wooden splint? So, the wooden splint burned and produced smoke because of *. It is because of the flame that the wooden splint was able to produce smoke. Here in question number 4, what is being asked is about the wooden splint."
8. Incomplete feedback statement	<i>Teacher's feedback:</i> "If you are adding more molecules of H ₂ O ₂ ..."
The assessor gave an incomplete feedback statement hence was difficult to interpret	<i>Peer's feedback:</i> "Yes it should only be..."

After coding for *feedback foci* and *moves*, the number of occurrences of each *feedback focus* and *moves* were determined for the teacher-feedback and peer-feedback groups. The number of occurrences was used to reveal which *feedback foci* and *moves* were frequently used by either the teacher and students' peers when giving feedback on drawings of chemical reactions involving and not involving identity transformation of chemical species.

3.7 Summary of the Methodology

A summary of this chapter is presented in Table 23. This is to facilitate understanding of the alignment between the research questions and the methodology.

Table 23 *Summary of the Research Questions, Data Collection Materials, Data Collected, and Data Analysis Tools and Techniques*

Research questions	Data collection materials	Data collected	Data analysis tools and techniques
			Independent samples t-test
1. Is there a difference in the order of difficulty in drawing chemical reactions?	Prior knowledge test		Scoring rubrics
	Paper folding test	Scores in the prior knowledge and paper folding tests	Inter-rater reliability (i.e., Intraclass Correlation Coefficient)
2. Is there a difference between the quality of students' drawings in the teacher-feedback group and peer-feedback group?	Worksheets		
	Recall test	Students' drawings	ANCOVA and Repeated measure ANCOVA
	Transfer tests		Effect sizes (Cohen's <i>d</i> and partial Eta squared)
3. What are the features of feedback that are valuable for supporting drawing to learn chemical reactions?	Video records	Video and audio transcripts showing the feedback given by the teacher (teacher-feedback group) and the students' peers (peer-feedback group)	Deductive and inductive coding
	Audio records		

Chapter 4 Background Comparison of Teacher-Feedback and Peer-Feedback Groups

This chapter presents the background results for the control variables: prior knowledge, spatial ability, physical conditions of the classroom, and the teacher's attitude towards the intervention. The chapter begins by presenting the comparison of prior knowledge about the types of chemical reactions and spatial ability between the two groups. Then, the number of students included in the quantitative analyses of the recall and transfer tests are presented. Results of the inter-rater reliability for the scores in the revised drawings, recall test, and transfer test are also discussed. The results for the time and setting of the intervention, and the teacher's fairness towards the two groups are examined. The chapter ends with a presentation of the evidence that teacher-feedback was at the *active* mode and peer-feedback was at the *interactive* mode of learning.

4.1 Prior Knowledge of the Teacher-Feedback and Peer-Feedback Groups

Before the intervention, the teacher-feedback group had 50 students while the peer-feedback group had 51 students. However, there were three students from the teacher-feedback group and two students from the peer-feedback group who missed at least one lesson from the intervention. Since these students did not complete the whole intervention, it was not reliable to assess their overall learning during the intervention. These students, who missed at least a lesson, were excluded from the statistical analyses of the prior knowledge test, spatial ability test, and revised drawings (reported in Chapter 5). Yet, their contributions to the study were not disregarded because their generated feedback was included in the qualitative analysis of feedback (reported in Chapters 9 and 10).

For the prior knowledge test, Cronbach's alpha as a measure of internal consistency was calculated by the researcher for all 40 items. Cronbach's alpha was found to be 0.70, which indicated that the items had acceptable reliability.

An independent-samples t-test was conducted to compare the mean scores of the students in the teacher-feedback ($N = 47$) and peer-feedback ($N = 49$) groups in the prior knowledge test (40 items). Given that Levene's test for homogeneity of variance was violated ($F = 4.11$, $p = 0.046$) a t-test not assuming homogeneous variances was calculated. Table 24 shows that there was no significant difference in the mean scores of the teacher-feedback ($M = 21.2$, $SD = 5.58$) and peer-feedback ($M = 22.8$, $SD = 3.96$) groups in the Prior Knowledge Test [$t(77.1) = -1.57$, $p = 0.12$]. This result of a non-significant difference suggests that students in the teacher-feedback and peer-feedback groups had comparable prior knowledge about the four types of chemical reactions.

Table 24 Results of Independent-Samples t-Test for the Two Groups' Scores in the Prior Knowledge Test

Group	N	Mean score (Full score = 40 pts.)	Standard deviation	F	Sig.	t	df	Sig. (2-tailed)
Teacher-feedback	47	21.2	5.58	4.11	0.046	-1.57	77.1	0.12
Peer-feedback	49	22.8	3.96					

4.2 Spatial Ability of the Teacher-Feedback and Peer-Feedback Groups

Cronbach's alpha as a measure of internal consistency was calculated by the researcher for all 20 items of the Paper Folding Test. Cronbach's alpha was found to be 0.81, which indicated that the items had good reliability.

An independent-samples t-test was conducted to compare the mean scores of the students in the teacher-feedback ($N = 47$) and peer-feedback ($N = 49$) groups in the Paper Folding Test (20 items). Given a violation of Levene's test for homogeneity of variance ($F = 7.07$, $p = 0.009$) a t-test not assuming homogeneous variances was calculated. Table 25

shows that there was a significant difference in the mean scores of the two groups in the Paper Folding Test [$t(76.6) = -2.02, p = 0.047$]. Scores of the peer-feedback group ($M = 16.5, SD = 2.59$) were significantly higher than the teacher-feedback group ($M = 15.1, SD = 3.68$). The effect size for this independent-samples t-test (Cohen's $d = 0.44$) was described as medium based on Cohen's (1988) convention. This result of significant difference suggests that students in the two groups did not have the same spatial ability as assessed by the Paper Folding Test. Hence, the spatial ability was identified as a covariate for the quality of drawings. To assess the differences between the two groups' quality of drawings, the effects of the covariate (spatial ability) were statistically removed. This was done via a One-Way Analysis of Covariance (ANCOVA) (Howitt & Cramer, 2017).

Table 25 *Results of Independent-Samples t-Test for the Two Groups' Scores in the Paper Folding Test*

Group	N	Mean score (Full score = 20 pts.)	Standard deviation	F	Sig.	t	df	Sig. (2- tailed)
Teacher- feedback	47	15.1	3.68	7.07	0.009	-2.02	76.6	0.047
Peer- feedback	49	16.5	2.59					

4.3 Number of Students in the Analysis of the Recall and Transfer Tests

This section presents the number of students in the teacher-feedback and peer-feedback groups that were included in the quantitative analyses of the recall and transfer tests a month after the intervention (reported in Chapter 6). There were students from the two groups who either did not take the test or had no answer (no drawing) in one or more items of the recall and/or transfer tests and so were excluded from the analyses. Table 26 shows the summary of the number of students in the two groups that were included and excluded in the

quantitative analyses of the recall and transfer tests. The contributions to the study of those excluded students were not disregarded because their generated feedback was included in the qualitative analysis of feedback.

Table 26 *Number of Students in the Two Groups for the Quantitative Analysis of the Recall and Transfer Tests a Month After the Intervention*

Group	No. of students	Recall test	Transfer test
Teacher-feedback	50	Included	47
		Excluded	3
Peer-feedback	51	Included	49
		Excluded	2

4.4 Inter-Rater Reliability

Inter-rater reliability using intraclass correlation coefficient (ICC) was performed on the scores of the revised drawings during the intervention, and drawings in the recall and transfer tests a month after the intervention. 20% of the sample (20 out of 101 students) was used. The drawings were randomly selected and independently assessed by two raters, i.e., the researcher (Rater 1) and a secondary chemistry teacher (Rater 2). A two-way random-effects model based on single rater type and absolute agreement definition along with 95% confidence intervals were used. A two-way random-effects model was used to generalize the reliability results to any raters who have the same characteristics as the two selected raters. Single rater type was used because despite there being two raters only the scores of Rater 1 were used as actual scores for the succeeding statistical analyses. Absolute agreement definition was used because the study was concerned with the extent to which the scores of Rater 1 equalled Rater 2. The 95% confidence interval described the range of values where there was a 95% chance that the true ICC value could be found (Koo & Li, 2016).

Consequently, the interpretation of the results was as follows: Values lower than 0.05

indicate poor reliability, those between 0.05 and 0.75 indicate moderate reliability, those between 0.75 and 0.90 indicate good reliability, and higher than 0.90 indicate excellent reliability.

4.4.1 Revised Drawings

This section presents the results of the ICC for the revised drawings of each type of chemical reaction (combination, decomposition, single displacement, and double displacement) and the two chemical reactions used for practice (extraction of iron and dissociation of ethanoic acid). Table 27 shows that the ICCs ranged from good to excellent reliability in the first round of scoring; except for the ‘dissociation of ethanoic acid’ where Rater 2 got confused with the ‘conservation of particles’ criterion of the scoring rubric. The chemical reaction was the dissociation of a weak acid, i.e., ethanoic acid (CH_3COOH). The description for each score of the ‘conservation of particles’ criterion asked for a comparison of the number of particles of the undissociated reactants and the number of both the dissociated and undissociated products. However, Rater 2 only compared the number of particles of the undissociated reactants and the number of the dissociated products leaving out the undissociated products. As a result, the interrater reliability for the chemical reaction was poor. Consequently, the two raters met to discuss and clarify the descriptions of the ‘conservation of particles’ criterion. After both raters agreed on the same understanding of the descriptions, they proceeded on independently scoring the drawings again (second round of scoring). After the second round of scoring, the inter-rater reliability for dissociation of ethanoic acid was determined to be excellent.

Table 27 Intraclass Correlation Coefficients for the Scores of the Two Raters on the Revised Drawings

Worksheet no.	Chemical reaction	Type of reaction	First round of scoring		Second round of scoring	
			ICC	Interpr.	ICC	Interpr.
I	$2\text{Fe}_2\text{O}_3(\text{s}) + 3\text{C}(\text{s}) \xrightarrow{\Delta} 4\text{Fe}(\text{s}) + 3\text{CO}_2(\text{g})$	Extraction of iron (Practice)	0.92	Excellent		
II	$\text{CH}_3\text{COOH}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{CH}_3\text{COO}^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$	Dissociation of ethanoic acid (Practice)	0.46	Poor	0.96	Excellent
1	$2\text{Mg}(\text{s}) + \text{O}_2(\text{g}) \rightarrow 2\text{MgO}(\text{s})$	Combination	0.80	Good		
2	$2\text{H}_2\text{O}_2(\text{aq}) \xrightarrow{\text{MnO}_2} 2\text{H}_2\text{O}(\text{l}) + \text{O}_2(\text{g})$	Decomposition	0.81	Good		
3	$\text{Mg}(\text{s}) + \text{CuCl}_2(\text{aq}) \rightarrow \text{Cu}(\text{s}) + \text{MgCl}_2(\text{aq})$	Single displacement	0.85	Good		
4	$\text{Na}_2\text{S}(\text{s}) + 2\text{HCl}(\text{aq}) \rightarrow \text{H}_2\text{S}(\text{g}) + 2\text{NaCl}(\text{aq})$	Double displacement	0.90	Good		

4.4.2 Recall Test

This section presents the inter-rater reliability for the scores of the drawings for each type of chemical reaction in the recall test one month after the intervention. Table 28 shows that the ICCs ranged from good to excellent reliability after one round of independently scoring the drawings.

Table 28 Intraclass Correlation Coefficients for the Scores of the Two Raters on the Drawings in the Recall Test a Month After the Intervention

Item	Chemical reaction	Type of reaction	ICC	Interpr
1	$2\text{Mg}(\text{s}) + \text{O}_2(\text{g}) \rightarrow 2\text{MgO}(\text{s})$	Combination	0.75	Good
2	$2\text{H}_2\text{O}_2(\text{aq}) \xrightarrow{\text{MnO}_2} 2\text{H}_2\text{O}(\text{l}) + \text{O}_2(\text{g})$	Decomposition	0.97	Excel.
3	$\text{Na}_2\text{S}(\text{s}) + 2\text{HCl}(\text{aq}) \rightarrow \text{H}_2\text{S}(\text{g}) + 2\text{NaCl}(\text{aq})$	D. displacement	0.93	Excel.
4	$\text{Mg}(\text{s}) + \text{CuCl}_2(\text{aq}) \rightarrow \text{Cu}(\text{s}) + \text{MgCl}_2(\text{aq})$	S. displacement	0.91	Excel.

4.4.3 Transfer Tests

This section presents the inter-rater reliability for the scores of the drawings of each type of chemical reaction in the transfer test one month after the intervention. Table 29 shows that the ICCs ranged from good to excellent reliability after one round of independently scoring the drawings.

Table 29 *Intraclass Correlation Coefficients for the Scores of the Two Raters on the Drawings in the Transfer Test a Month After the Intervention*

Item	Chemical reaction	Type of reaction	ICC	Interpr.
1	$2A_2B_{(l)} \rightarrow 2A_{2(g)} + B_{2(g)}$	Decomposition	0.89	Good
2	$CaCl_{2(aq)} + 2KOH_{(aq)} \rightarrow Ca(OH)_{2(s)} + 2KCl_{(aq)}$	Double displacement	0.95	Excellent
3	$2Be_{(s)} + O_{2(g)} \rightarrow 2BeO_{(s)}$	Combination	0.93	Excellent
4	$Ca_{(s)} + H_2SO_{4(aq)} \rightarrow CaSO_{4(aq)} + H_{2(g)}$	Single displacement	0.94	Excellent

4.5 Time and Setting of the Intervention

This section reports on the time and setting of the intervention. The two treatment groups had each lesson of the intervention at the same time (i.e., either morning or afternoon) on the same day except for practice lesson three (see Appendix H). During practice lesson three (drawing of the dissociation of ethanoic acid), the peer-feedback group had their practice lesson a day after the teacher-feedback group had theirs. Lessons conducted on the same day helped minimise if they could not prevent students from one treatment group communicate about the intervention to the other group (i.e., treatment diffusion effects).

The two treatment groups also had each lesson in the same classroom (i.e., either the Physical Science Laboratory or Biological Science Laboratory; see Appendix H) with the same seating arrangement for each student-team. There was only one instance during the intervention when the two treatment groups used different classrooms, albeit they still were

science laboratories and they followed the same seating arrangement. This one instance of different classrooms for the two treatment groups was during lesson 10 (giving feedback on drawings of the single displacement reaction); the peer-feedback group used the Chemistry Laboratory while the teacher-feedback group used the Physical Science Laboratory.

The lessons were at a similar time each day (either morning or afternoon) and in the same classroom ensuring that physical conditions (i.e., temperature of the surroundings, ventilation, lighting, seating arrangement and noise quality) were kept comparable for both treatment groups. These physical conditions could have potentially influenced students' behaviour towards the intervention.

4.6 Teacher's Fairness Towards the Intervention

This section presents the results of the classroom observation done by the researcher on how the teacher conducted the intervention between the two treatment groups. Overall, 11 observations were done. Observations for lessons five and six were combined. Table 30 presents the six criteria from the classroom observation checklist and the assessment of the extent (i.e., SD – strongly disagree, D – disagree, A – agree, and SA – strongly agree) to which the teacher met these criteria. The frequency of the extent to which the teacher met each criterion across the 11 observations was determined. The teacher's fairness towards the two treatment groups in implementing the intervention was monitored using these criteria.

Table 30 *Frequency of the Extent to Which the Teacher Met Each Criterion in Implementing the Intervention*

Criteria	SD	D	A	SA
1. The teacher made explicit the difference between the two conditions (teacher-feedback and peer-feedback)	0	0	4	7
2. The teacher followed thoughtfully what was stated in the corresponding teacher's guide for the two classes	0	0	7	4
3. In both classes, the teacher exhibited the same personality and attitude	0	0	3	8
4. In both classes, the teacher used language and terminologies that students can easily understand	0	0	10	1
5. In both classes, the teacher encouraged students to express their own ideas freely	0	0	0	11
6. The teacher showed mastery of the subject matter in both classes	0	0	1	10
7. In both classes, the teacher exhibited mastery in delivering the lesson	0	0	3	8
8. The teacher gave both classes the same number of activities (except for the feedback part)	0	0	0	11
9. The teacher used English as the medium of instruction in both classes	0	0	0	11

Based on Table 30, the researcher saw that the teacher fulfilled all the six criteria listed in the classroom observation checklist. In dealing with the two treatment groups the teacher exhibited the same personality and attitudes while teaching them. The teacher also taught the same topics and utilised the same learning activities for the two treatment groups although making a distinction between the two feedback conditions. These results suggest that the teacher demonstrated fairness in implementing the intervention in the two treatment groups.

4.7 Teacher-Feedback at the *Active* Mode and Peer-Feedback at the *Interactive* Mode

This section presents evidence that the teacher-feedback group was at the *active* mode and peer-feedback group was at the *interactive* mode of learning. Based on the ICAP theory (Chi, 2009, 2021; Chi & Wylie, 2014) learning is described to be *active* if it includes some

form of psychomotor work that requires focused attention. Cognitive process during *active* learning involves emphasising specific aspects of the psychomotor task, which causes activation of prior knowledge. Then the new information is integrated into the activated prior knowledge and reinforces it. In my study students' (unrevised) drawings before receiving feedback were artefacts of their prior knowledge. Teacher-feedback was at the *active* mode because during the whole-class presentation (see Figure 6) students received feedback from the teacher that prompted them to focus on specific aspects of their drawing (both a cognitive and psychomotor task). Since students revised their drawings based on teacher-feedback, students integrated the new information (teacher-feedback) into their activated prior knowledge (unrevised drawings). Such integration of the new information to prior knowledge was expressed through drawing revision. Students revised drawings demonstrating that they did not just passively receive the teacher-feedback (new information).

Interactive mode of learning according to the ICAP theory involves dialogues that meet two criteria: (1) there is sufficient degree of turn-taking. And (2) utterances are jointly *constructive* meaning that both partners (not just one person) worked together to generate an output (i.e., an artefact) beyond what was originally provided (Chi, 2009, 2021; Chi & Wylie, 2014). Cognitive process during *interactive* learning involves co-inferring, i.e., partners take turns in mutually creating new insights. In this study, the round-robin way of giving and receiving peer-feedback (see Figure 7) enabled the students to engage in a joint dialogue and not in an individual dialogue where only one student dominated the conversation. The first criterion was satisfied because students took equal turns in being an assessee and assessor for each other. More so, the second criterion was achieved because the dialogues during peer-feedback were constructive as they were focused on improving their drawings.

4.8 Summary of Results

The following seven points summarize the background results:

1. The teacher-feedback and peer-feedback groups had comparable prior knowledge of the types of chemical reactions (see Section 4.1).
2. Spatial ability had been identified as a covariate. The teacher-feedback and peer-feedback groups did not have comparable spatial ability as assessed by the Paper Folding Test (see Section 4.2).
3. There were varying number of students in the two feedback groups that were included in the quantitative analyses of the revised drawings during the intervention, and recall and transfer tests a month after the intervention (see Sections 4.1 and 4.3).
4. In scoring the revised drawings during the intervention, and recall and transfer tests one month after the intervention, the extent of agreement between the two raters ranged from good to excellent (see Section 4.4).
5. The physical conditions of the intervention (i.e., time and setting) were kept the same for the two feedback groups (see Section 4.5).
6. In implementing the intervention, the teacher was fair towards the two feedback groups and was able to distinguish between the two feedback sources (see Section 4.6).
7. Teacher-feedback was at the *active* mode while peer-feedback was at the *interactive* mode of learning (see Section 4.7).

Chapter 5 Teacher-Feedback and Peer-Feedback Groups' Drawings

During the Intervention

This chapter presents the results of the quantitative analyses on the students' drawings of the four types of chemical reactions, both from the teacher-feedback and peer-feedback groups, during the intervention. The presentation of results in this chapter and in Chapter 6 answers the first two specific research questions: (1) *Is there a difference in the order of difficulty in drawing chemical reactions?* and (2) *Is there a difference between the quality of students' drawings in the teacher-feedback group and peer-feedback group?* The chapter presents the variations in the scores of the two groups across the types of chemical reactions. Then, the results of the test of difference in the overall scores and scores for each type of chemical reaction on the quality of drawings of the two groups are shown.

5.1 Differences in the Variations of Scores of the Two Groups on the Different Types of Chemical Reactions

Repeated measure ANCOVA was conducted to determine if there were statistically significant differences between the adjusted mean score percentages of each group across the four types of chemical reactions in the revised drawings while controlling for spatial ability. The adjusted mean score percentages were used (instead of the adjusted mean scores) because percentages describe how well the groups scored relative to the full scores for drawing each reaction type. Table 31 presents the results of the repeated measure ANCOVA for the teacher-feedback group. The scores in the drawings between combination and double displacement reactions, and between decomposition and single displacement reactions did not differ significantly. However, the scores in the drawings between either combination or double displacement reactions, and either decomposition or single displacement reactions had significant differences. These results of the repeated measure ANCOVA suggest that the teacher-feedback group had comparable adjusted mean score percentages on the revised

drawings of both decomposition and single displacement reactions and comparable adjusted mean score percentages on the revised drawings of combination and double displacement reactions. However, the adjusted mean score percentages for both combination and double displacement reactions were modest than that of decomposition and single displacement reactions.

Table 31 *Differences in the Adjusted Mean Score Percentages for Each Type of Chemical Reaction in the Teacher-Feedback Group*

Chemical reaction	Chemical reaction	Mean difference	Sig.
Combination	Decomposition	-11.7	0.001
	S. displacement	-8.80	0.015
	D. displacement	-1.58	1.00
Decomposition	Combination	11.7	0.001
	S. displacement	2.92	1.00
	D. displacement	10.1	<0.001
Single displacement	Combination	8.80	0.015
	Decomposition	-2.92	1.00
	D. displacement	7.22	<0.001
Double displacement	Combination	1.58	1.00
	Decomposition	-10.1	<0.001
	S. displacement	-7.22	<0.001

Table 32 presents the results of the repeated measure ANCOVA for the peer-feedback group. The scores in the drawings of decomposition reaction were statistically higher than that of the other three types of chemical reactions. Additionally, between the scores in the drawings of combination and either single displacement or double displacement reactions, no significant difference was observed. Yet, between single displacement and double displacement reactions, a significant difference was observed. These results of the repeated measure ANCOVA suggest that the peer-feedback group had the highest adjusted mean score percentage in the revised drawings of decomposition reaction. More so the peer-feedback group had comparable adjusted mean score percentages in the revised drawings of the three

other types of chemical reactions, i.e., combination, single displacement, and double displacement reactions. These adjusted mean score percentages in the revised drawings of the three other types of chemical reactions were relatively lower compared to the teacher-feedback group.

Table 32 *Differences in the Adjusted Mean Score Percentages for Each Type of Chemical Reaction in the Peer-Feedback Group*

Chemical reaction	Chemical reaction	Mean difference	Sig.
Combination	Decomposition	-16.1	<0.001
	S. displacement	-2.90	1.00
	D. displacement	5.43	0.067
Decomposition	Combination	16.1	<0.001
	S. displacement	13.2	<0.001
	D. displacement	21.5	<0.001
S. displacement	Combination	2.90	1.00
	Decomposition	-13.2	<0.001
	D. displacement	8.33	0.004
D. displacement	Combination	-5.43	0.067
	Decomposition	-21.5	<0.001
	S. displacement	-8.33	0.004

Students from both groups consistently had the highest quality of drawings in the decomposition reaction. Decomposition reaction was the only chemical reaction that did not involve identity transformation. Drawings of combination and double displacement reactions were found to be the lowest two for both groups (with no significant difference between the two reactions for both groups). In the teacher-feedback group the quality of drawings of combination and double displacement reactions were comparable. In the peer-feedback group the quality of drawings of combination was comparable with both single displacement and double displacement reactions. These three chemical reactions, i.e., combination, single displacement and double displacement reactions involved changes in the identity of the particles. Hence, the quality of drawings of the combination reaction may serve as

representative for the chemical reactions involving identity transformation and drawings of decomposition reaction for the chemical reaction not involving identity transformation. Based on these outcomes, qualitative results of the quantity and quality of feedback generated by the two groups during the intervention are reported in Chapters 9 and 10 for both chemical reactions involving and not involving identity transformation, respectively.

5.2 Overall Scores (Worksheets 1 to 4)

Cronbach's alpha was calculated by the researcher for all the four worksheets used during the intervention. Cronbach's alpha was found to be 0.81, which indicated that the worksheets had good reliability.

This section reports on the results of the One-way Analysis of Covariance (ANCOVA) conducted to determine if there was a statistically significant difference between students of the teacher-feedback group ($N = 47$) and peer-feedback group ($N = 49$) on their overall scores while controlling for their spatial ability (The two groups did not have the same spatial ability, see Section 4.2).

In conducting ANCOVA, two important assumptions were fulfilled before the analysis: Homogeneity of variance (the variances of the two groups were similar) and homogeneity of regression (the regression slope was constant for the two groups, i.e., the relationship between the covariate and the dependent variable was the same for both groups) (Howitt & Cramer, 2017). Levene's test indicated that the assumption of the homogeneity of variance was met ($F = 1.22, p = 0.27$). An F test on the interaction of the group with spatial ability yielded non-significant results [$F(1,87) = 0.052, p = 0.82$], which indicated that the assumption of homogeneity of regression was also met.

Table 33 shows that there was a significant difference in the adjusted mean scores of the two groups in their overall scores for their drawings, [$F(1, 88) = 59.6, p < 0.001$] while controlling for spatial ability. The adjusted mean score of the teacher-feedback group

(Adjusted $M = 90.3$, $SD = 9.88$) was significantly higher than the peer-feedback group (Adjusted $M = 73.5$, $SD = 10.6$).

Table 33 Results of ANCOVA for Students' Overall Scores (Worksheets 1 to 4) in Their Revised Drawings of the Four Types of Chemical Reactions

Full score	Group	N (Total = 96)	Adjusted mean score	Adjusted mean score %	F	Sig.	Cohen's d	partial Eta squared
114 pts.	Teacher-feedback	47	90.3	79.2	59.6	<0.001	1.66	0.40
	Peer-feedback	49	73.5	64.5				

The *Cohen's d* effect size for the difference was 1.66, which is large, based on Cohen's (1988) convention. The percentile standing was 95.5th percentile for the *Cohen's d* of 1.66. This percentile standing means that a student from the teacher-feedback group who garnered the average score (adjusted mean score = 90.3) had a higher score than 95.5% of students from the peer-feedback group (Becker, 2000; Coe, 2002). Partial Eta squared (η_p^2) indicated the percentage of variation in the students' scores that can be attributed to the group condition, i.e., teacher-feedback or peer-feedback while controlling for spatial ability. In Table 33, 40% (or 0.40) of the variation in the students' overall scores in their revised drawings (Worksheets 1 to 4) can be attributed to the group condition, i.e., teacher-feedback or peer-feedback while controlling for spatial ability. This partial Eta squared value was large (Cohen, 1988, 1992; Draper, 2019; Miles & Shevlin, 2001; Rosenthal, 1996). These results on the large effect sizes suggest that overall, the teacher-feedback group had a remarkably higher quality of revised drawings of the four types of chemical reactions than the peer-feedback group.

5.3 Scores for Each Type of Chemical Reaction

This section reports on the results of the One-way ANCOVA conducted to determine if there was a statistically significant difference between students of the teacher-feedback group and peer-feedback group on their scores for the drawings of each of the four types of chemical reactions (Worksheets 1 to 4) while controlling for their spatial ability.

Levene's test indicated that the assumption of the homogeneity of variance was met for all types of chemical reactions. Then, an F test on the interaction of the group with spatial ability yielded non-significant results indicating that the assumption of homogeneity of regression was also met for all types of chemical reactions. Table 34 presents the results of Levene's test and F test for all types of chemical reactions.

Table 34 *Results of the Tests for the Homogeneity of Variance and Regression Assumptions for Each Type of Chemical Reaction (Worksheets 1 to 4)*

Types of chemical reaction	Variance		Levene's test		F test	
	Teacher-feedback group	Peer-feedback group	F	Sig.	F	Sig.
1 (Combination)	10.4	6.0	1.53	0.22	0.20	0.66
2 (Decomposition)	13.8	11.0	0.07	0.80	0.00	0.96
3 (Single displacement)	9.4	12.8	0.36	0.55	0.59	0.45
4 (Double displacement)	22.0	27.8	0.64	0.43	1.61	0.21

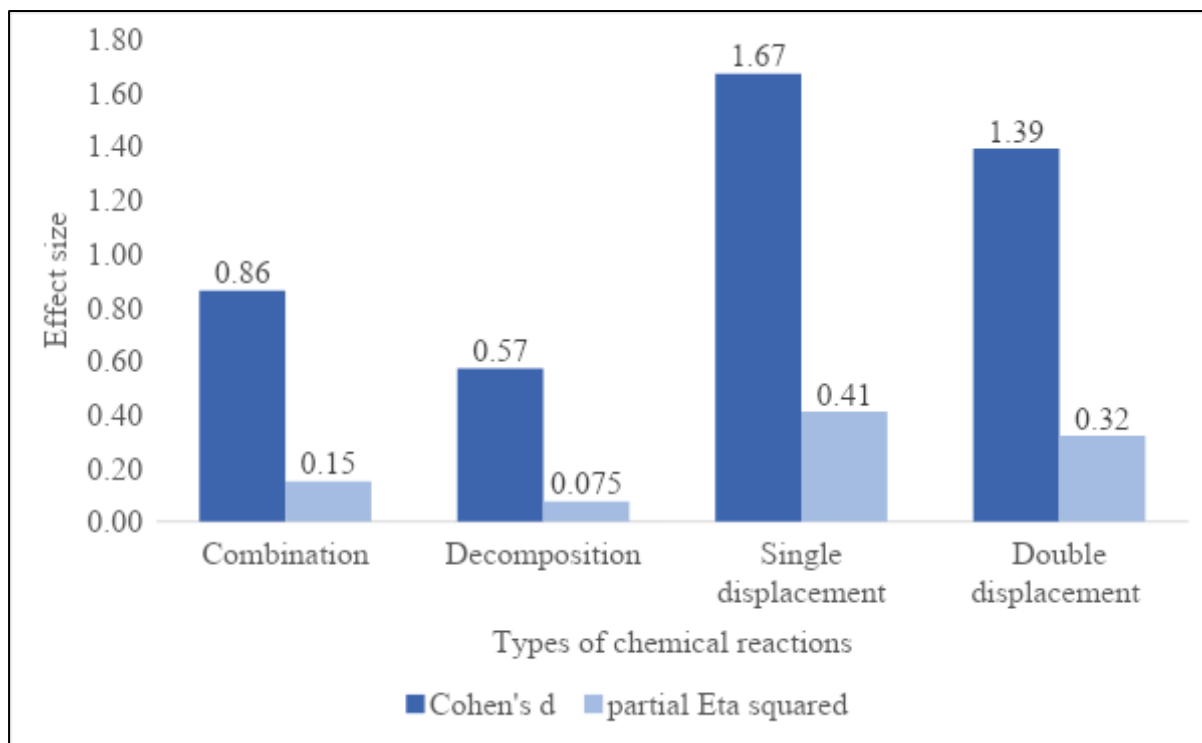
Table 35 shows that there were significant differences in the adjusted mean scores of the two groups in their drawings of all four types of chemical reactions while controlling for spatial ability. The adjusted mean scores of the teacher-feedback group were significantly higher than the peer-feedback group.

Table 35 Results of ANCOVA for Students' Scores in their Revised Drawings of Each Type of Chemical Reaction (Worksheets 1 to 4)

Full score (Total = 114 pts.)	Grp.	N	Adjusted mean score	Adjusted mean score %	F	Sig.	Cohen's <i>d</i>	partial Eta squared
1 Combination 22 pts.	TF	47	16.1	73.2	15.9	<0.001	0.86	0.15
	PF	49	13.7	62.1				
2 Decomposition 27 pts.	TF	47	23.0	85.2	7.2	0.009	0.57	0.075
	PF	49	21.0	77.8				
3 S. displacement 29 pts.	TF	47	24.0	82.8	60.2	<0.001	1.67	0.41
	PF	49	18.6	64.2				
4 D. displacement 36 pts.	TF	47	27.1	75.3	41.8	<0.001	1.39	0.32
	PF	49	20.2	56.1				

Figure 12 and Table 35 show the effect sizes (i.e., Cohen's *d* and partial Eta squared) between the two groups on each type of chemical reaction. The effect sizes were the lowest for decomposition reaction: Cohen's *d* = 0.57 (69th percentile standing; medium) and η_p^2 = 0.075 (7.5%; medium). The effect sizes for all the other three types of chemical reactions were large especially for single displacement and double displacement reactions.

Figure 12 *Effect Sizes for Each Type of Chemical Reaction in the Revised Drawings During the Intervention*



These results suggest that students who received feedback from the teacher had higher quality revised drawings for all four types of chemical reactions than those in the peer-feedback group. For combination, single displacement, and double displacement reactions, the magnitudes of difference in the quality of the revised drawings of the two groups were remarkable while for decomposition reaction it was modest.

5.4 Variations in the Scores of the Two Groups on the Different Types of Chemical Reactions

Bar graphs of the adjusted mean score percentages (y-axis) of the teacher-feedback group (Figure 13) and peer-feedback group (Figure 14) across types of chemical reactions (x-axis) were constructed. Figures 13 and 14 show that in all four types of chemical reactions, students in the teacher-feedback group had higher adjusted mean score percentages than the peer-feedback group; and the difference was significant across all four types of chemical

reactions as reported in Section 5.3. Figure 13 shows that for teacher-feedback group, the adjusted mean score percentage for decomposition reaction was the highest followed by single displacement and double displacement reactions. The lowest for the teacher-feedback group was combination reaction. Figure 14 shows that for the peer-feedback group, decomposition reaction was the highest followed by single displacement and combination reactions. The lowest for peer-feedback group was double displacement reaction.

Figure 13 *Adjusted Mean Score Percentages of the Teacher-Feedback Group for Each Type of Chemical Reaction in Their Revised Drawings*

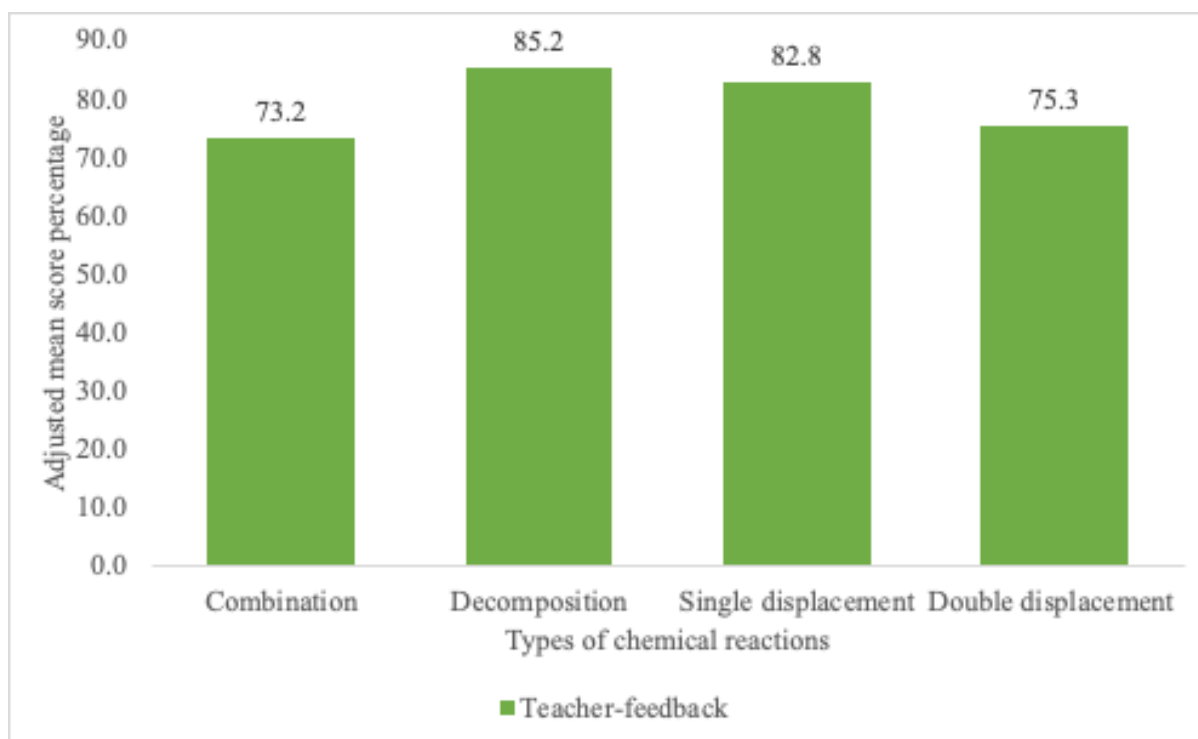
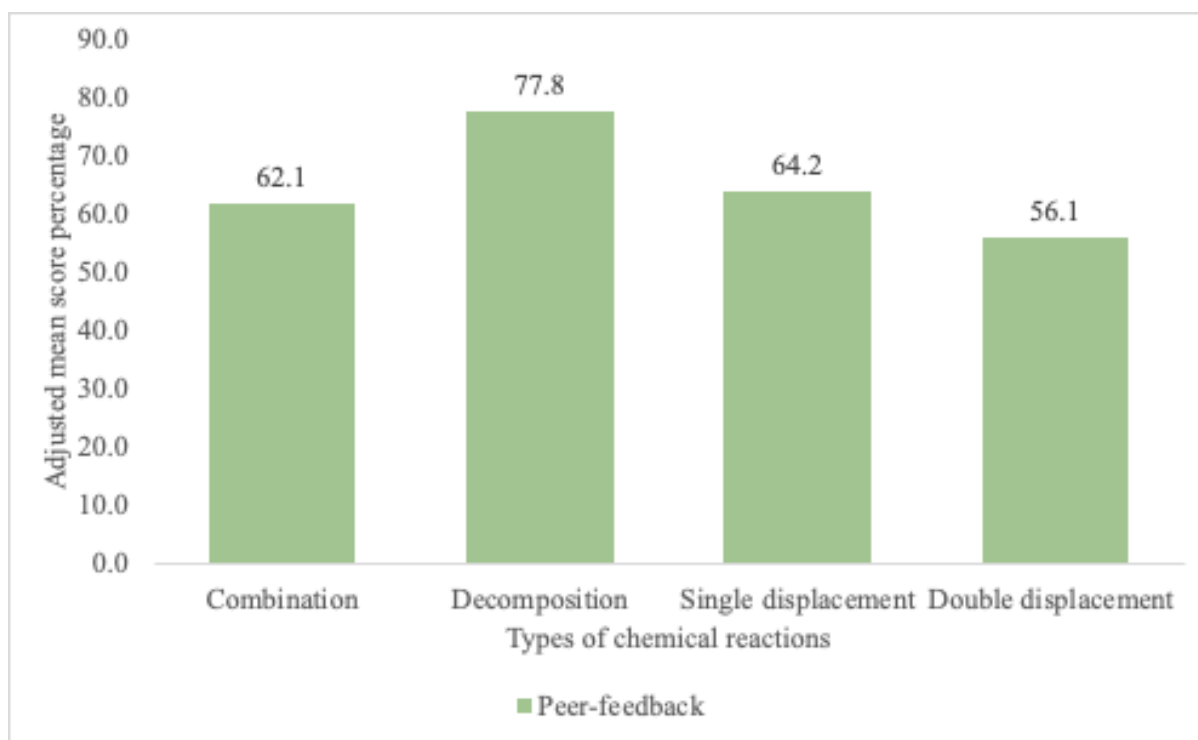


Figure 14 *Adjusted Mean Score Percentages of the Peer-Feedback Group for Each Type of Chemical Reaction in Their Revised Drawings*



Chapter 6 Teacher-Feedback and Peer-Feedback Groups' Drawings a Month After the Intervention

This chapter presents the results of the quantitative analyses on the students' drawings from the teacher-feedback and peer-feedback groups in their recall and transfer tests a month after the intervention. This chapter begins with presenting the results of the analyses on the variations of scores of the two groups on the different reaction types in the recall test. Then the results of the difference between the quality of drawings of the two groups are compared. The same sequence is used in presenting the results of the analyses of the quality of drawings of the two groups in the transfer test.

6.1 Recall Test

6.1.1 Differences in the Variations of Scores of the Two Groups on the Different Types of Chemical Reactions

Repeated measure ANCOVA was conducted to determine if there were statistically significant differences between the adjusted mean score percentages of each group across the four types of chemical reactions in the recall test while controlling for spatial ability. The adjusted mean score percentages were used (instead of the adjusted mean scores) because they accurately described how well the groups scored relative to the full scores for each type of chemical reaction. Table 36 presents the results of the repeated measure ANCOVA for the teacher-feedback group. Table 36 shows that no significant differences existed between the adjusted mean score percentages of combination and decomposition reactions and between double displacement and single displacement reactions. However, significant differences existed between either combination or decomposition reaction and that of either double displacement or single displacement reaction. These results of the repeated measure ANCOVA suggest that the teacher-feedback group had the highest quality of drawings on both combination and decomposition reactions. Nevertheless, the teacher-feedback group had

a comparable quality of drawings on double displacement and single displacement reactions, which was lower than that of combination and decomposition reactions.

Table 36 *Differences in the Teacher-Feedback Group's Adjusted Mean Score Percentages for Each Type of Chemical Reaction in the Recall Test One Month After the Intervention*

Chemical reaction	Chemical reaction	Mean difference	Sig.
Combination	Decomposition	0.39	1.00
	D. displacement	14.9	<0.001
	S. displacement	14.8	<0.001
Decomposition	Combination	-0.39	1.00
	D. displacement	14.5	<0.001
	S. displacement	14.5	<0.001
D. displacement	Combination	-14.9	<0.001
	Decomposition	-14.5	<0.001
	S. displacement	-0.086	1.00
S. displacement	Combination	-14.8	<0.001
	Decomposition	-14.5	<0.001
	D. displacement	0.086	1.00

For the peer-feedback group, the results of the repeated measure ANCOVA is presented in Table 37 and shows a similar result to that of the teacher-feedback group. No significant differences existed between the adjusted mean score percentages of decomposition and combination reactions and between double displacement and single displacement reactions. However, significant differences existed between either decomposition or combination and that of either double displacement or single displacement reactions. These results of the repeated measure ANCOVA suggest that the peer-feedback group had the highest quality of drawings on both combination and decomposition reactions. Additionally, like the teacher-feedback group the peer-feedback group had a comparable quality of drawings on double displacement and single displacement reactions which was lower than that of combination and decomposition reactions.

Table 37 Differences in the Peer-Feedback Group's Adjusted Mean Score Percentages for Each Type of Chemical Reaction in the Recall Test One Month After the Intervention

Chemical reaction	Chemical reaction	Mean difference	Sig.
Combination	Decomposition	-4.33	1.00
	D. displacement	11.4	0.001
	S. displacement	16.3	<0.001
Decomposition	Combination	4.33	1.00
	D. displacement	15.7	<0.001
	S. displacement	20.7	<0.001
D. displacement	Combination	-11.4	0.001
	Decomposition	-15.7	<0.001
	S. displacement	4.98	0.32
S. displacement	Combination	-16.3	<0.001
	Decomposition	-20.7	<0.001
	D. displacement	-4.98	0.32

6.1.2 Overall Scores (Items 1 to 4)

One-way Analysis of Covariance (ANCOVA) was conducted to determine if there was a statistically significant difference between students of the teacher-feedback group ($N = 47$) and peer-feedback group ($N = 49$) on their overall scores in the recall test (Items 1 to 4, full score is 114 pts.) while controlling for their spatial ability.

Levene's test indicated that the assumption of homogeneity of variance was met ($F = 3.89$, $p = 0.052$). An F test on the interaction of the group with spatial ability yielded non-significant results [$F(1, 92) = 0.95$, $p = 0.33$] indicating that the assumption of homogeneity of regression was also met. Table 38 shows that there was a significant difference in the adjusted mean scores of the two groups in their overall scores in the recall test, [$F(1, 93) = 22.9$, $p < 0.001$] while controlling for spatial ability. The adjusted mean score of the teacher-feedback group (Adjusted $M = 74.6$, $SD = 10.7$) was significantly higher than the peer-feedback group (Adjusted $M = 63.0$, $SD = 12.3$).

Table 38 Results of ANCOVA for Students' Overall Scores (Items 1 to 4) in their Recall Test a Month After the Intervention

Full score	Group	N (Total = 96)	Adjusted mean score	Adjusted mean score %	F	Sig.	Cohen's <i>d</i>	partial Eta squared
114 pts.	Teacher-feedback	47	74.6	65.4	22.9	<0.001	1.01	0.20
	Peer-feedback	49	63.0	55.3				

The effect sizes for the analysis of the overall scores were: (a) Cohen's $d = 1.01$, which was described to be large based on Cohen's (1988) convention. The percentile standing, which described the percentage of peer-feedback students surpassed by a teacher-feedback student who garnered the average score (adjusted mean score) (Becker, 2000; Coe, 2002) was 84th percentile for this Cohen's d value. This percentile standing means that a student from the teacher-feedback group who garnered the average score (adjusted mean score = 74.6) had a higher score than 84% of students from the peer-feedback group; (b) partial Eta squared, $\eta_p^2 = 0.20$. Partial Eta squared indicated the percentage of variation in the students' scores that could be attributed to the group condition, i.e., teacher-feedback or peer-feedback while controlling for spatial ability. This partial Eta squared value means that 20% of the variation in the students' overall scores in the recall test (Items 1 to 4) could be attributed to the group condition, i.e., teacher-feedback or peer-feedback while controlling for spatial ability. This partial Eta squared value was large (Cohen, 1988, 1992; Draper, 2019; Miles & Shevlin, 2001; Rosenthal, 1996). These results on the effect sizes suggest that overall, the teacher-feedback group had a remarkably higher quality of drawings in the recall test than the peer-feedback group.

6.1.3 Scores for Each Type of Chemical Reaction

ANCOVA was conducted to determine if there is a statistically significant difference between students of the teacher-feedback group and peer-feedback group on their scores for each type of chemical reaction in the recall test while controlling for their spatial ability. Levene's test indicated that the assumption of homogeneity of variance was met for all types of chemical reactions except for combination. ANCOVA is a robust statistical procedure and the assumption of homogeneity of variance is often violated with relatively minor effects (Howell, 2013). Yet for combination reaction the largest variance which was that of the peer-feedback group = 14.1 was no more than four times the smallest variance which was that of the teacher-feedback group = 6.1. Hence, ANCOVA was still most likely to be valid for combination reaction (Howell, 2013). Also, the F test on the interaction of the group with spatial ability yielded non-significant results for all four types of chemical reactions. This F test results indicate that the assumption of homogeneity of regression was met for all four types of chemical reactions. Table 39 presents the results of the Levene's test and F test for all four types of chemical reactions in the recall test.

Table 39 *Results of the Tests for the Homogeneity of Variance and Regression Assumptions for Each Type of Chemical Reaction in the Recall Test a Month After the Intervention (Items 1 to 4)*

Types of chemical reactions	Variance		Levene's test		F test	
	Teacher-feedback group	Peer-feedback group	F	Sig.	F	Sig.
1 (Combination)	6.1	14.1	5.50	0.021	0.53	0.47
2 (Decomposition)	12.1	27.9	3.26	0.074	0.093	0.76
3 (Double displacement)	24.1	22.2	0.044	0.83	2.28	0.13
4 (Single displacement)	23.8	26.6	1.31	0.26	1.03	0.31

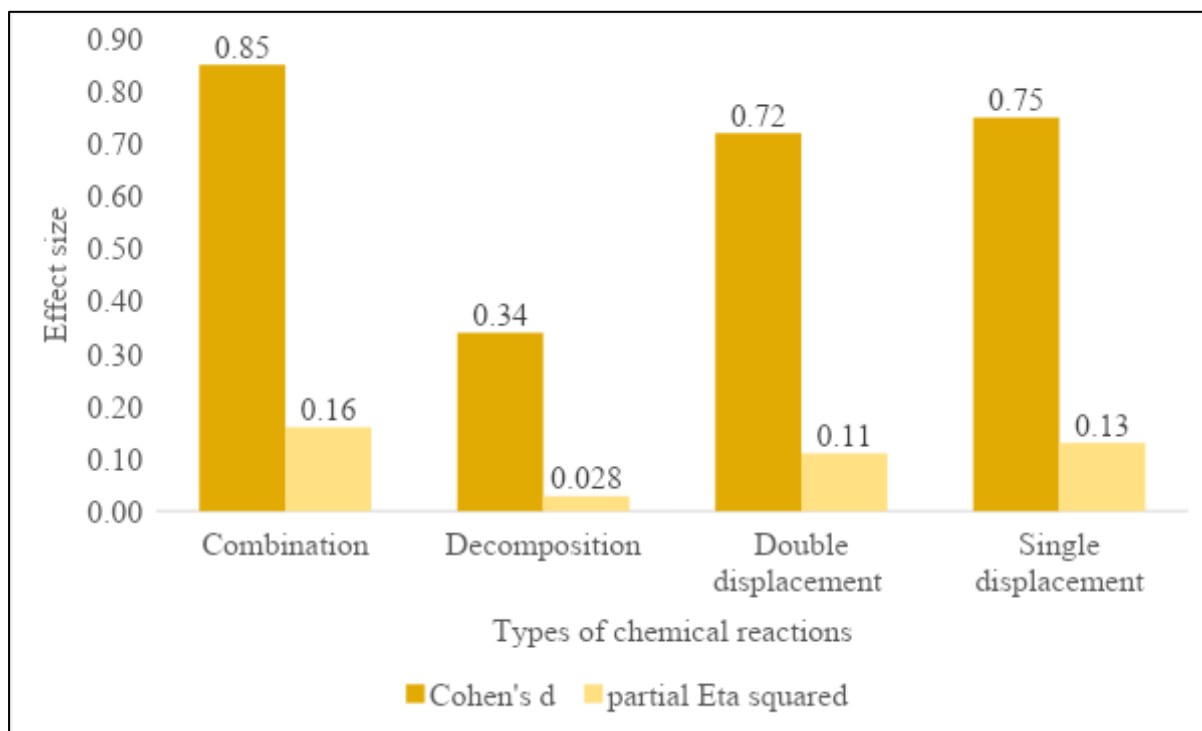
Moreover Table 40 shows that significant differences existed between the adjusted mean scores of the two groups for their scores in the combination, double displacement, and single displacement reactions but not for decomposition reaction while controlling for spatial ability. The adjusted mean scores of the teacher-feedback group were significantly higher than the peer-feedback group for combination, double displacement, and single displacement reactions but not for decomposition reaction.

Table 40 *Results of ANCOVA for Students' Scores for Each Type of Chemical Reaction in the Recall Test a Month After the Intervention (Items 1 to 4)*

Full score (Total = 114 pts.)	Grp.	N	Adjusted mean score	Adjusted mean score %	F	Sig.	Cohen's <i>d</i>	partial Eta squared
1 Combination 22 pts.	TF	47	16.3	74.1	17.2	<0.001	0.85	0.16
	PF	49	13.6	61.8				
2 Decomposition 27 pts.	TF	47	19.6	72.6	2.70	0.10	0.34	0.028
	PF	49	18.1	67.0				
3 D. displacement 36 pts.	TF	47	21.4	59.4	11.8	0.001	0.72	0.11
	PF	49	18.0	50.0				
4 S. displacement 29 pts.	TF	47	17.1	59.0	13.3	<0.001	0.75	0.13
	PF	49	13.3	45.9				

The effect sizes (i.e., Cohen's *d* and partial Eta squared) for each type of chemical reaction in the recall test are also presented in Figure 15 and Table 40. The lowest effect sizes were observed for decomposition reaction: Cohen's *d* = 0.34 (small and 62nd percentile standing) and $\eta_p^2 = 0.028$ (2.8%; small). For double displacement: Cohen's *d* = 0.72 (medium and 76th percentile standing) and $\eta_p^2 = 0.11$ (11%; medium); For single displacement: Cohen's *d* = 0.75 (medium and 76th percentile standing) and $\eta_p^2 = 0.13$ (13%; medium). The highest effect sizes were observed for combination reaction: Cohen's *d* = 0.85 (large and 79th percentile standing) and $\eta_p^2 = 0.16$ (16%; large).

Figure 15 *Effect Sizes for Each Type of Chemical Reaction in the Recall Test a Month After the Intervention*



These results on the effect sizes suggest that in recalling how to accurately draw the combination reaction a month after the intervention teacher-feedback students produced remarkably higher quality of drawings compared to peer-feedback students. In recalling how to accurately draw double displacement and single displacement reactions teacher-feedback students still had higher quality of drawings compared to peer-feedback students. However, the differences between the two groups' quality of drawings for double displacement and single displacement reactions were modest. In recalling how to accurately draw the decomposition reaction, students from both groups had comparable quality of drawings.

6.1.4 Variation of Scores on Different Types of Chemical Reactions in the Teacher-Feedback and Peer-Feedback Groups

Bar graphs of the adjusted mean score percentages (y-axis) of the teacher-feedback group (Figure 16) and peer-feedback group (Figure 17) across the types of chemical reactions (x-axis) were constructed. In both Figures 16 and 17, for all four types of chemical reactions,

the teacher-feedback group had higher mean score percentages than the peer-feedback group. As identified in Section 6.1.3 for the decomposition reaction the teacher-feedback group's adjusted mean score was not significantly higher than the peer-feedback group. Both Figures 16 and 17 show that the adjusted mean score percentages of the two groups varied largely. For the teacher-feedback group, values ranged from 59.0% to 74.1%. Combination was the highest followed by decomposition, double displacement and single displacement. For the peer-feedback group values ranged from 45.9% to 67.0%. Decomposition was the highest followed by combination, double displacement, and single displacement.

Figure 16 *Adjusted Mean Score Percentages of the Teacher-Feedback Group for Each Type of Chemical Reaction in the Recall Test a Month After the Intervention*

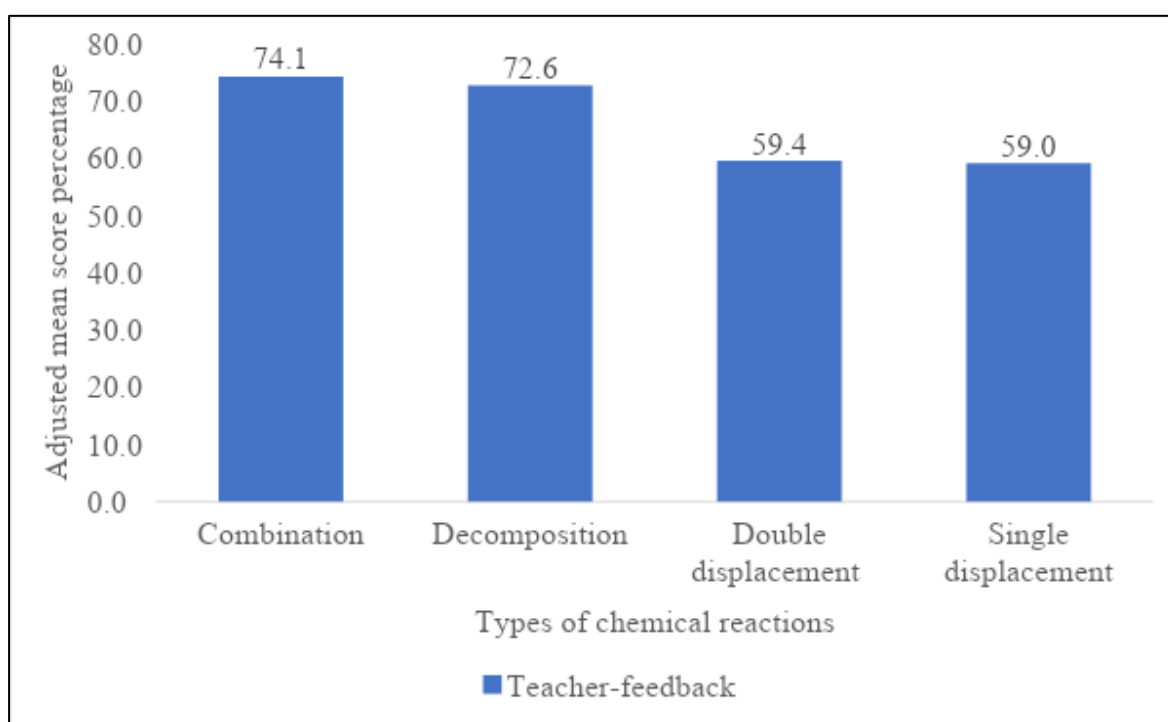
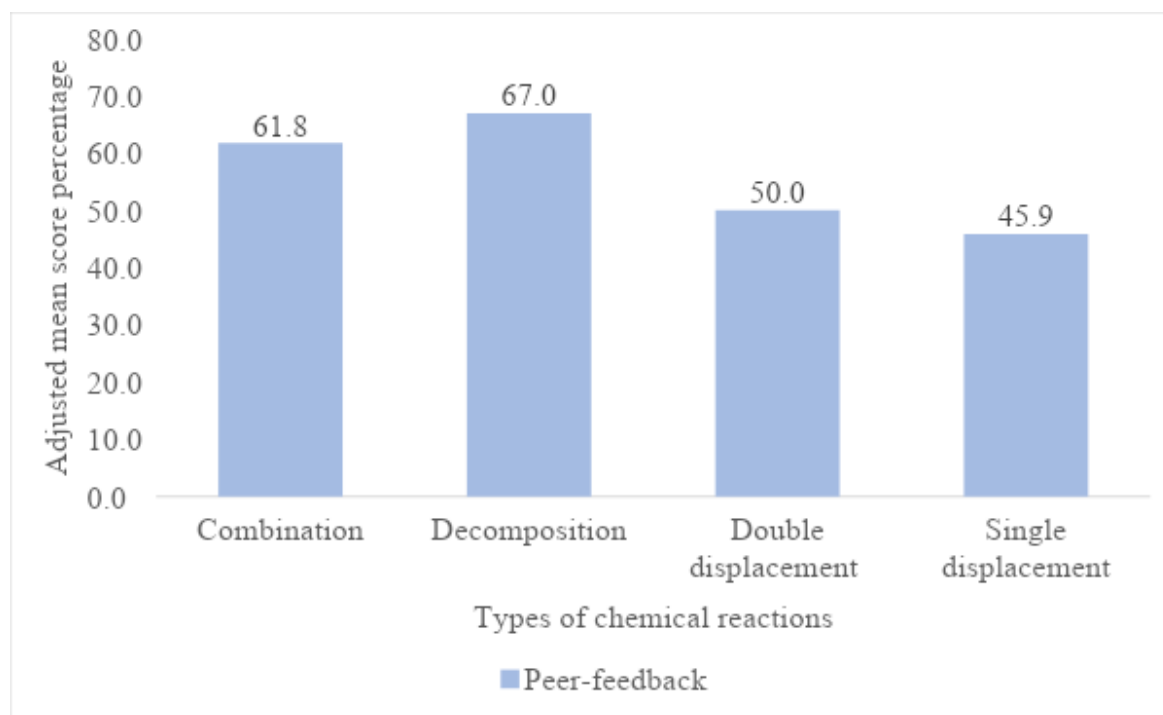


Figure 17 *Adjusted Mean Score Percentages of the Peer-Feedback Group for Each Type of Chemical Reaction in the Recall Test a Month After the Intervention*



6.2 Transfer Test

Cronbach's alpha as a measure of internal consistency was determined for the transfer test one month after the intervention. The alpha reliability for the transfer test was found to be 0.70. This alpha reliability value was considered acceptable (i.e., 0.6 or 0.7) as identified by van Griethuijsen et al. (2015) and Taber (2018b).

6.2.1 Differences in the Variations of Scores of the Two Groups on the Different Types of Chemical Reactions

Repeated measure ANCOVA was conducted to determine if there were statistically significant differences between the adjusted mean score percentages of each group across the four types of chemical reactions in the transfer test while controlling for spatial ability. The adjusted mean score percentages were used (instead of the adjusted mean scores) because they accurately described how well the groups scored relative to the full scores for each type of chemical reaction in the transfer test. Table 41 presents the results of this repeated measure

ANCOVA for the teacher-feedback group. Table 41 shows that for the teacher-feedback group decomposition was significantly higher than all the other three types of chemical reactions while single displacement was significantly lower than all the other three types of chemical reactions. Significant differences existed between either combination or double displacement and other types of chemical reactions. The results of the repeated measure ANCOVA show that a month after the intervention the teacher-feedback group's highest quality drawing of chemical reaction in the transfer test was decomposition followed by combination then double displacement reaction, while the least quality drawing was that of single displacement.

Table 41 *Differences in the Teacher-Feedback Group's Adjusted Mean Score Percentages for Each Type of Chemical Reaction in the Transfer Test a Month After the Intervention*

Chemical reaction	Chemical reaction	Mean difference	Sig.
Decomposition	D. displacement	31.4	<0.001
	Combination	7.16	0.042
	S. displacement	37.6	<0.001
D. displacement	Decomposition	-31.4	<0.001
	Combination	-24.2	<0.001
	S. displacement	6.16	0.029
Combination	Decomposition	-7.16	0.042
	D. displacement	24.2	<0.001
	S. displacement	30.4	<0.001
S. displacement	Decomposition	-37.6	<0.001
	D. displacement	-6.16	0.029
	Combination	-30.4	<0.001

For the peer-feedback group Table 42 presents the results of the repeated measure ANCOVA. In Table 42, decomposition was significantly higher than all the other three types of chemical reactions. Additionally, there was no significant difference between double displacement and single displacement reactions, although either double displacement or single displacement differed significantly from combination. The results of the repeated

measure ANCOVA show that a month after the intervention, the peer-feedback group's highest quality drawing of chemical reaction in the transfer test was decomposition followed by combination reaction. Whereas the least quality drawing was not only single displacement but also double displacement.

Table 42 *Differences in the Peer-Feedback Group's Adjusted Mean Score Percentages for Each Type of Chemical Reaction in the Transfer Test a Month After the Intervention*

Chemical reaction	Chemical reaction	Mean difference	Sig.
Decomposition	D. displacement	39.1	<0.001
	Combination	14.4	0.001
	S. displacement	45.9	<0.001
D. displacement	Decomposition	-39.1	<0.001
	Combination	-24.6	<0.001
	S. displacement	6.84	0.11
Combination	Decomposition	-14.4	0.001
	D. displacement	24.6	<0.001
	S. displacement	31.5	<0.001
S. displacement	Decomposition	-45.9	<0.001
	D. displacement	-6.84	0.11
	Combination	-31.5	<0.001

6.2.2 Overall Scores (Items 1 to 4)

One-way Analysis of Covariance (ANCOVA) was conducted to determine if there was a statistically significant difference between the students of the teacher-feedback group ($N = 47$) and peer-feedback group ($N = 49$) in the transfer test (Items 1 to 4, full score is 132 pts.) while controlling for their spatial ability.

Levene's test indicated that the assumption of homogeneity of variance was met ($F = 0.078$, $p = 0.78$). An F test on the interaction of the group with spatial ability yielded non-significant results [$F(1, 82) = 3.27$, $p = 0.074$] indicating that the assumption of homogeneity of regression was also met. Table 43 shows that there was a significant difference in the adjusted mean scores of the two groups in their overall scores in their transfer test, [$F(1, 83)$

= 20.5, $p < 0.001$] while controlling for spatial ability. The adjusted mean score of the teacher-feedback group (Adjusted $M = 71.8$, $SD = 17.3$) was significantly higher than the peer-feedback group (Adjusted $M = 55.9$, $SD = 14.5$).

Table 43 *Results of ANCOVA for Students' Overall Scores (Items 1 to 4) in Their Transfer Test a Month After the Intervention*

Full score	Group	N (Total = 96)	Adjusted mean score	Adjusted mean score %	F	Sig.	Cohen's d	partial Eta squared
132 pts.	Teacher-feedback	47	71.8	54.4	20.5	<0.001	1.00	0.20
	Peer-feedback	49	55.9	42.4				

The effect sizes for the analysis of the overall scores were: (a) Cohen's $d = 1.00$, which was described to be large based on Cohen's (1988) convention. The percentile standing, which described the percentage of students from the peer-feedback group surpassed by a student from the teacher-feedback group who garnered the average score (adjusted mean score) (Becker, 2000; Coe, 2002), was 84th percentile for this Cohen's d value. This percentile standing means that a student from the teacher-feedback group who garnered the average score (adjusted mean score = 71.8) had a higher score than 84% of students from the peer-feedback group; (b) partial Eta squared, $\eta_p^2 = 0.20$. Partial Eta squared indicated the percentage of variation in the students' scores that could be attributed to the group condition, i.e., teacher-feedback or peer-feedback while controlling for spatial ability. This partial Eta squared means that 20% of the variation in the students' overall scores in the transfer test (Items 1 to 4) could be attributed to the group condition, i.e., teacher-feedback or peer-feedback while controlling for spatial ability. This partial Eta squared value was large (Cohen, 1988, 1992; Draper, 2019; Miles & Shevlin, 2001; Rosenthal, 1996). These results

suggest that overall, the teacher-feedback group had a remarkable higher quality of drawings in the transfer test than the peer-feedback group.

6.2.3 Scores for Each Type of Chemical Reaction

ANCOVA was conducted to determine if there was a statistically significant difference between students of the teacher-feedback group and peer-feedback group on their scores for each type of chemical reaction in the transfer test while controlling for their spatial ability. Levene's test indicated that the assumption of homogeneity of variance was met for all four types of chemical reactions. More so, the F test on the interaction of the group with spatial ability yielded non-significant results for all four types of chemical reactions. This F test results indicate that the assumption of homogeneity of regression was also met for all four types of chemical reactions. Table 44 presents the results of the Levene's test and F test for all four types of chemical reactions in the transfer test a month after the intervention.

Table 44 *Results of the Tests for the Homogeneity of Variance and Regression Assumptions for Each Type of Chemical Reaction in the Transfer Test a Month After the Intervention (Items 1 to 4)*

Types of chemical reactions	Variance		Levene's test		F test	
	Teacher-feedback group	Peer-feedback group	F	Sig.	F	Sig.
1 (Decomposition)	21.3	18.6	0.19	0.67	2.44	0.12
2 (Double displacement)	52.6	42.4	0.17	0.68	2.59	0.11
3 (Combination)	10.0	12.7	1.52	0.22	0.66	0.42
4 (Single displacement)	64.3	39.3	0.017	0.90	1.17	0.28

Table 45 shows that significant differences existed between the adjusted mean scores of the two groups in their scores for three out of four types of chemical reactions in the transfer test namely: double displacement, combination, and single displacement while controlling for spatial ability. For decomposition however no significant difference existed

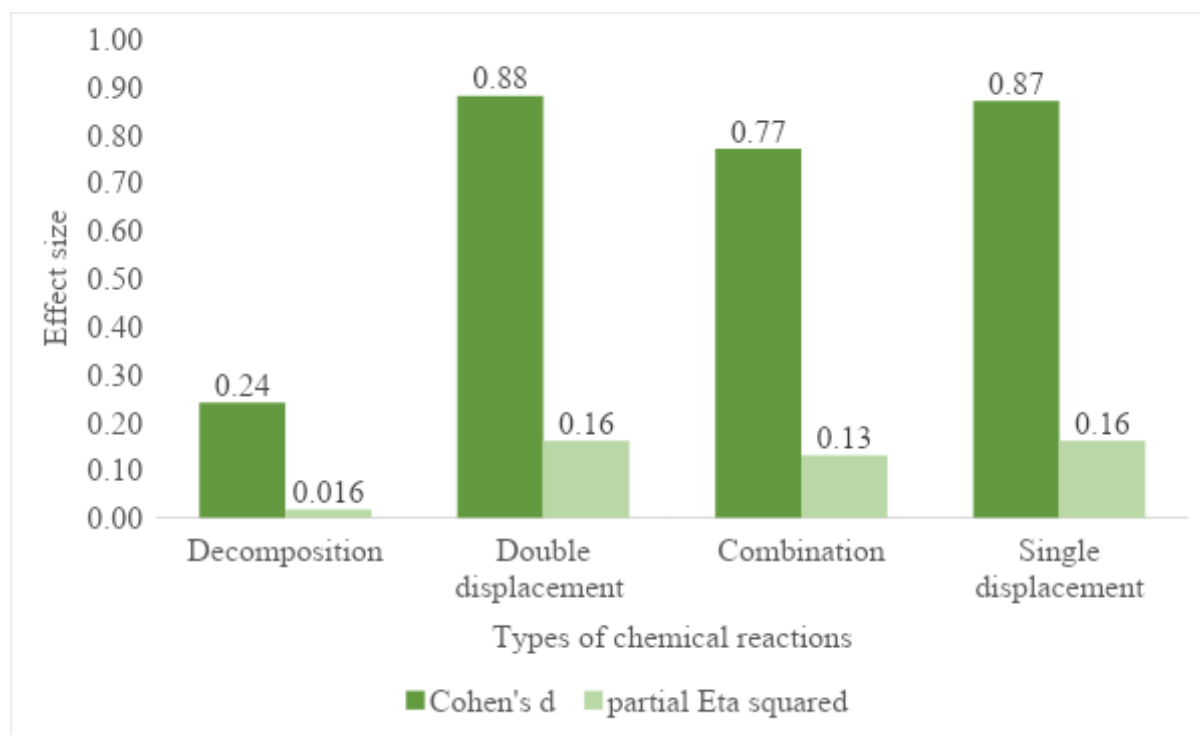
between the adjusted mean scores of the two groups. In all types of chemical reactions, except for the decomposition, the adjusted mean scores of the teacher-feedback group were significantly higher than the peer-feedback group.

Table 45 *Results of ANCOVA for Students' Scores for Each Type of Chemical Reaction in the Transfer Test a Month After the Intervention*

Full score (Total = 132 pts.)	Grp.	N	Adjusted mean score	Adjusted mean score %	F	Sig.	Cohen's <i>d</i>	partial Eta squared
1 Decomposition 25 pts.	TF	47	19.3	77.2	1.34	0.25	0.24	0.016
	PF	49	18.2	72.8				
2 D. displacement 42 pts.	TF	47	19.6	46.7	15.6	<0.001	0.88	0.16
	PF	49	13.7	32.6				
3 Combination 22 pts.	TF	47	15.4	70.0	12.0	0.001	0.77	0.13
	PF	49	12.8	58.2				
4 S. displacement 43 pts.	TF	47	17.4	40.5	15.3	<0.001	0.87	0.16
	PF	49	11.2	26.0				

Additionally, Figure 18 and Table 45 show the effect sizes (Cohen's *d* and partial Eta squared) between the two groups on each type of chemical reaction. Figure 18 shows that the lowest effect size was observed for decomposition reaction: Cohen's *d* = 0.24 (small and 58th percentile standing) and $\eta_p^2 = 0.016$ (1.6%; small). The effect sizes for the other remaining types of chemical reactions were large. For combination reaction: Cohen's *d* = 0.77 (large and 79th percentile standing) and $\eta_p^2 = 0.13$ (13%; medium to large). The effect sizes for double displacement reaction: Cohen's *d* = 0.88 (large and 82nd percentile standing) and $\eta_p^2 = 0.16$ (16%; large), and single displacement reaction: Cohen's *d* = 0.87 (large and 82nd percentile standing) and $\eta_p^2 = 0.16$ (16%; large) were comparable and the highest.

Figure 18 *Effect Sizes for Each Type of Chemical Reaction in the Transfer Test a Month After the Intervention*



In accurately drawing the submicroscopic understanding of the types of chemical reactions different from what were studied during the intervention those students who received teacher-feedback had a higher quality of drawings of double displacement, combination, and single displacement reactions compared to those who received peer-feedback. Moreover, the differences in the quality of the drawings between the two groups for these three types of chemical reactions were pronounced. For decomposition reaction, both groups had a comparable quality of drawings. Peer-feedback seemed to be equally useful to teacher-feedback when drawing the decomposition reaction.

6.2.4 Variation of Scores on Different Types of Chemical Reactions in the Teacher-Feedback and Peer-Feedback Groups

Bar graphs of the adjusted mean score percentages (y-axis) of the teacher-feedback group (Figure 19) and peer-feedback group (Figure 20) across the types of chemical reactions (x-axis) were constructed. Both Figures 19 and 20 present that there was a large variation in the adjusted mean scores percentages of both groups: teacher-feedback group (40.5% to 77.2%) and peer-feedback group (26.0% to 72.8%). Yet, in all types of chemical reactions (except decomposition), the teacher-feedback group had significantly higher quality of drawings than the peer-feedback group (see Section 6.2.3).

Figure 19 *Adjusted Mean Score Percentages of the Teacher-Feedback Group for Each Type of Chemical Reaction in the Transfer Test a Month After the Intervention*

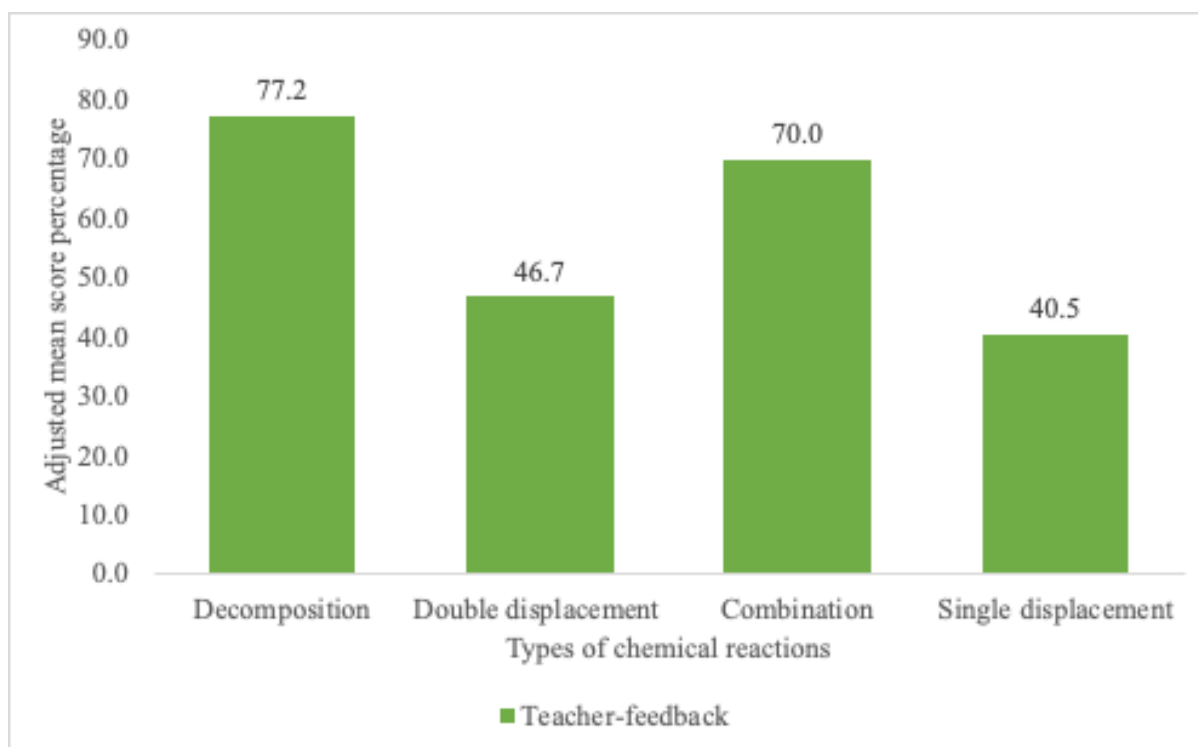
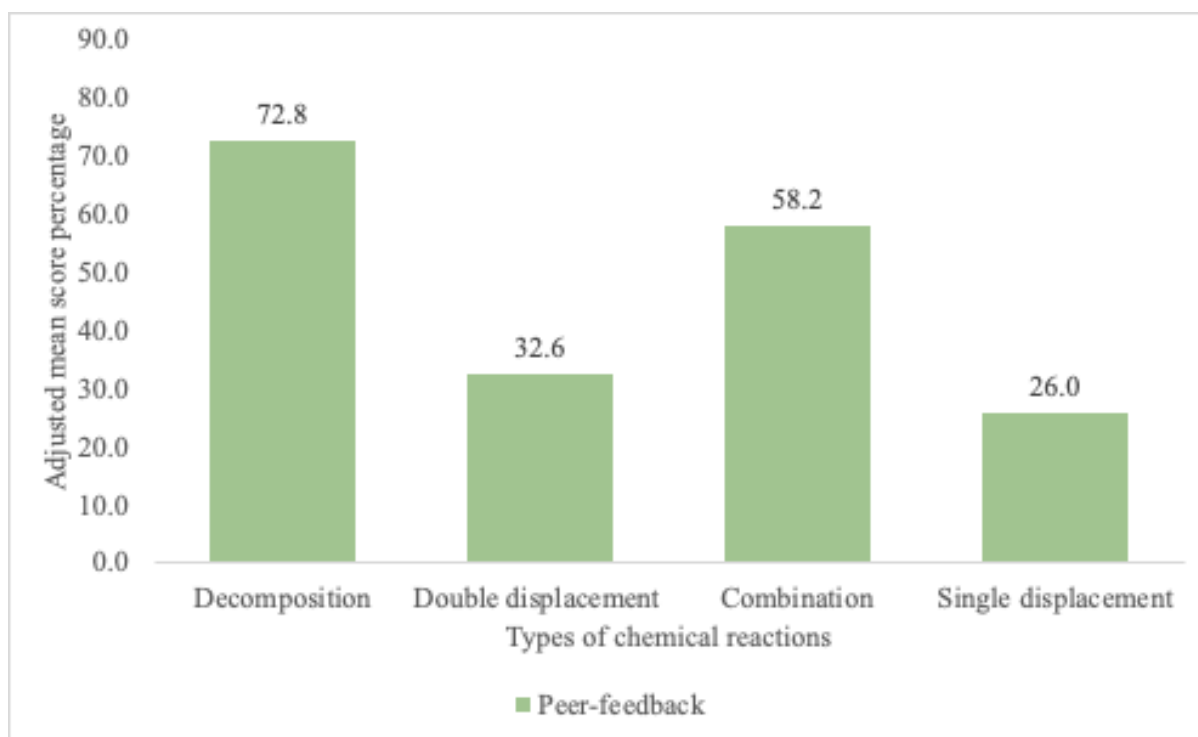


Figure 20 *Adjusted Mean Score Percentages of the Peer-Feedback Group for Each Type of Chemical Reaction in the Transfer Test a Month After the Intervention*



Chapter 7 Order of Difficulty in Drawing Different Types of Chemical Reactions

This chapter discusses the order of difficulty in drawing different reaction types based on the synthesis of the quantitative results. The chapter begins with a summary of notable findings from Chapters 5 and 6. Then the discussion of how the identity of the chemical species particularly the features of the ions involved affected the difficulty of drawing reactions is presented.

7.1 Notable Quantitative Findings

In drawing different reaction types the visual element on the identity of the species as either atoms, molecules or ions is pertinent in describing the difficulty of drawing the reactions. Even so difficulty in drawing ions may also vary depending on their features, i.e., the number of atoms that make up the ionic species and its charges. Table 46 presents the adjusted mean score percentages of the two groups during and a month after the intervention.

Table 46 *Adjusted Mean Score Percentages of the Two Feedback Groups in the Four Types of Chemical Reactions Overtime*

Types of chemical reactions	Teacher-feedback			Peer-feedback		
	During	One month after		During	One month after	
		Recall	Transfer		Recall	Transfer
Combination	73%	74%	70%	62%	62%	58%
Decomposition	85%	73%	77%	78%	67%	73%
Single displacement	83%	59%	41%	64%	46%	26%
Double displacement	75%	59%	47%	56%	50%	33%

While there is no immediately obvious pattern in each column, there are notable observations which show that in both groups, there was similar order of difficulty in drawing the different reaction types.

Students did best in drawing decomposition reactions

In the teacher-feedback group the scores in drawing the decomposition reactions during the intervention and in the transfer test were the highest among all reaction types. In fact, the recall test was also the highest as there was no statistical significance between the score (73%) and that of combination (74%). Also, there was an increase in the scores from the recall test (73%) to the transfer test (77%) whereas the scores for the other reaction types decreased.

In the peer-feedback group the scores for decomposition during the intervention, recall test, and transfer test were consistently the highest among all reaction types. There was also an increase in the scores from the recall test (67%) to the transfer test (73%) while scores for the other reaction types decreased.

Students did well in drawing combination reactions

In the teacher-feedback group the score in drawing combination reaction during the intervention was the lowest among all reaction types. But notably the score (73%) was almost equal to the recall test (74%). This was in contrast with other reaction types where the recall test scores were always lower than that of during the intervention. The recall test was the highest while the transfer test was second highest among all reaction types.

In the peer-feedback group the score in drawing combination reaction during the intervention was second lowest (after double displacement) among all reaction types. But this score remained the same in the recall test (62% = 62%), while the other reaction types decreased. Also, both recall and transfer tests were the second highest among all reaction types. Focusing on the post-tests for both groups drawing of combination reactions seems to be more challenging than drawing decomposition but is less challenging than the two displacement reactions.

Drawing displacement reactions was most challenging

Scores in the two displacement reactions (i.e., single and double), particularly in the post-tests, were often not statistically different from each other and were lower than decomposition and combination reactions. Hence, these two reactions were analysed together as *displacement reactions* albeit subtleties between them are also discussed.

In the teacher-feedback group the scores for drawing both displacement reactions during the intervention were lower than decomposition although single displacement (83%) was statistically higher than double displacement (75%). In the post-tests scores of both displacement reactions were statistically lower than those of decomposition and combination reactions. In the recall tests both scores were the same (59%). Notably in the transfer test, single displacement (41%) was statistically lower than double displacement (47%).

In the peer-feedback group, both displacement reactions during the intervention were statistically lower than decomposition though the score for single displacement (64%) was statistically higher than double displacement (56%). In the post-tests scores in both recall (50%; 46%) and transfer tests (33%; 26%) were not statistically different yet these were statistically lower than decomposition and combination reactions. Focusing on the post-tests for both groups drawing of displacement reactions seems to be the most challenging among all reaction types.

In both feedback groups during the intervention, it was expected that students scored higher in drawing the single displacement than the double displacement reaction. However, the result on the transfer test of the teacher-feedback group where students scored lower in the single displacement than the double displacement reaction was unexpected (both results are elaborated in the next section).

7.2 The Order of Difficulty in Drawing Chemical Reactions Varies Depending on the Identity of the Chemical Species Including its Features

The same order of difficulty in drawing chemical reactions was observed from both feedback sources. Drawing decomposition was the least challenging followed by combination while the displacement reactions were the most challenging. This order of complexity depends on the identity of the chemical species and its features.

Decomposition reaction

The following are the chemical equations for the decomposition reactions during the intervention (and recall test) and in the transfer test:

During (and Recall): $2\text{H}_2\text{O}_{2(\text{aq})} \rightarrow 2\text{H}_2\text{O}_{(\text{l})} + \text{O}_{2(\text{g})}$ decomposition of aqueous hydrogen peroxide

Transfer: $2\text{A}_2\text{B}_{(\text{l})} \rightarrow 2\text{A}_{2(\text{g})} + \text{B}_{2(\text{g})}$ hypothetical decomposition of liquid A_2B

Drawing decomposition reaction was found by both groups to be the least challenging among all reaction types. The quality of drawings was consistently the best among all reaction types during the intervention and in the post-tests. Also, both groups improved from recalling how to draw a familiar reaction (i.e., decomposition of aqueous hydrogen peroxide) to drawing an unfamiliar one (i.e., hypothetical decomposition of liquid A_2B).

Both decomposition reactions involved only atomic and/or molecular species. The changes involved changing from compound molecules to compound molecules (i.e., H_2O_2 to H_2O) and from compound molecules to elemental molecules (i.e., H_2O_2 to O_2 , A_2B to A_2 and B_2). The particles did not transform or change from atoms or molecules to ions where they change from bearing no electric charge to charged species (or vice versa).

The students seemed to experience fewer challenges in drawing chemical species as atoms and molecules regardless of the source of feedback. Drawing chemical species as

consisting of atoms and molecules appeared to be more intuitive for students than drawing ions. Drawing the decomposition reaction could be accomplished using the simple particle model of chemical reaction, which requires less abstractions (i.e., fewer conceptual ideas) than the atomic model (Cheng, 2018; Cheng & Gilbert, 2017). The simple particle model considers the reactants as made up of discrete particles (represented concretely as circles) that spatially rearranged during the reaction to form the products. The atomic model considers not only the spatial rearrangement of the reactant particles, but also the interaction between their electrons during the breaking and formation of covalent bonds as additional conceptual idea. Nevertheless, the simple particle model was adequate to represent the changes from compound molecules to compound molecules (i.e., H_2O_2 to H_2O) and from compound molecules to elemental molecules (i.e., H_2O_2 to O_2 , A_2B to A_2 and B_2).

Combination reaction

The chemical equations for the combination reactions during the intervention (and recall test) and in the transfer test are as follows:

During (and Recall): $2\text{Mg}_{(\text{s})} + \text{O}_{2(\text{g})} \rightarrow 2\text{MgO}_{(\text{s})}$ Combustion of solid magnesium

Transfer: $2\text{Be}_{(\text{s})} + \text{O}_{2(\text{g})} \rightarrow 2\text{BeO}_{(\text{s})}$ Combustion of solid beryllium

The students in both feedback groups maintained the quality of drawing the combination reaction from during the intervention to the recall test, whereas drawings of the other reaction types were reduced in quality. Also, in both the recall and transfer tests of the two feedback groups combination was better than the two displacement reactions but not for decomposition.

The combination reaction involved atomic, molecular, and ionic species. It is unlike the decomposition reactions that only involved atomic and molecular species, and the two

displacement reactions that involved more ionic species. The combustion of solid magnesium involved magnesium atoms (Mg), diatomic oxygen molecules (O_2), magnesium ions (Mg^{2+}) and oxide ions (O^{2-}). Combustion of beryllium involved similar particles. Notably, the two ions in the formula unit combined in a 1:1 ratio.

Based on the findings on drawing decomposition reaction students can represent atoms and molecules readily. This is because, as previously discussed, drawing chemical reactions involving atomic and/or molecular species could be accomplished using the simple particle model, which is less complex than the atomic model (Cheng, 2018; Cheng & Gilbert, 2017). In drawing the combination reaction during the intervention, 96% of the students in the peer-feedback group (49 out of 51) accurately drew magnesium as atoms; 57% (29 out of 51) accurately drew oxygen as diatomic molecules. Notably no student drew magnesium oxide as made up of magnesium and oxide ions. In the teacher-feedback group, only 21% of the students (10 out 48) accurately drew magnesium and oxide ions; whereas 83% (40 out 48) accurately drew magnesium atoms and 63% (30 out of 48) accurately drew oxygen molecules. Matter being made up of indivisible ‘atoms’ has been dominant in chemistry instruction (Taber, 2003), which likely contributes to students’ preferential use of the particle model over the atomic model of chemical reactions. There are chemistry books that represent atoms as indivisible entities that rearranged during chemical reaction (Atkins, 2013, p. 46) or use the particle model more often than the atomic model to illustrate chemical reactions (Chang, 1994, p. 84; Hill & Petrucci, 1996, p. 84; Rendle, n.d., pp. 121-123). Consequently, students prefer models of atoms that show them as concrete entities and not as abstract ideas (Harrison & Treagust, 1996).

The quality of drawing combination reaction in both feedback groups during the intervention was unexpectedly one of the two lowest (together with double displacement) among all reaction types (unlike in the post-tests). This is likely because drawing

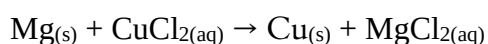
combination reaction was the first drawing activity. Students from both groups had just started with the intervention and were still new to learning to draw chemical reactions.

Displacement reaction

The following are the chemical equations for the two displacement reactions during the intervention (and recall test) and in the transfer test:

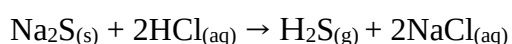
During (and Recall Test):

Single displacement



Reaction between solid magnesium and aqueous copper (II) chloride

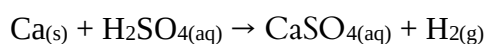
Double displacement



Reaction between solid sodium sulfide and hydrochloric acid

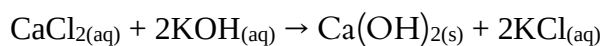
Transfer Test

Single displacement



Reaction between solid calcium and sulfuric acid

Double displacement



Reaction between aqueous solutions of calcium chloride and potassium hydroxide

Drawing both single and double displacement reactions was the most challenging for students among all the reaction types regardless of feedback source. In both recall and transfer tests, both groups' drawings of the two displacement reactions were lower than decomposition and combination. In fact, the quality of both groups' drawings of both displacement reactions were comparable in both post-tests, i.e., recall test for teacher-feedback: 59% = 59%; and peer-feedback: 50% > 46% but not statistically significant while in the transfer test for peer-feedback group: 33% > 26% but not statistically significant.

During the intervention, both groups' drawings of the two displacement reactions were lower than decomposition but not for combination (except in the peer-feedback group where combination was higher than double displacement). As previously discussed, drawing the combination reaction, although it involved a smaller number of ionic species than the two displacement reactions, was the first drawing activity and students were still new to learning how to draw chemical reactions.

Both groups' drawings of single displacement during the intervention as expected were better than double displacement reactions. This is because the single displacement reaction involved two atomic species (i.e., Mg and Cu) and three ionic species (i.e., Cu^{2+} , Mg^{2+} and Cl^-) whereas double displacement reaction had only one molecular species (i.e., H_2S) and four ionic species (i.e., Na^+ , S^{2-} , H^+ , Cl^-). It was expected that drawing reactions involving ions are more challenging for students than drawing atoms and/or molecules. This view was consistent with the finding from the data for decomposition and combination reactions.

In the recall test drawing the two displacement reactions became comparable for both feedback sources. This is probably because the effects of the intervention had started to fade. Over time it became challenging for the students in both feedback groups to recognize ions. Consequently, it became equally challenging for the students to draw both displacement

reactions that involved the highest number of ionic species among all the reaction types. In the teacher-feedback group adjusted mean scores for drawing the identity of the particles in the two displacement reactions decreased from the intervention to the recall test: single displacement is from 5.27 to 3.28; and double displacement is from 9.41 to 5.24. In the peer-feedback group adjusted mean scores for drawing single displacement (which was the most challenging) remained the lowest from 2.54 during the intervention to 2.56 in the recall test. For double displacement, it decreased from 5.00 to 3.91. Teacher-feedback students' recall of drawing reactions involving particle identity transformation diminished as the reaction became more complex.

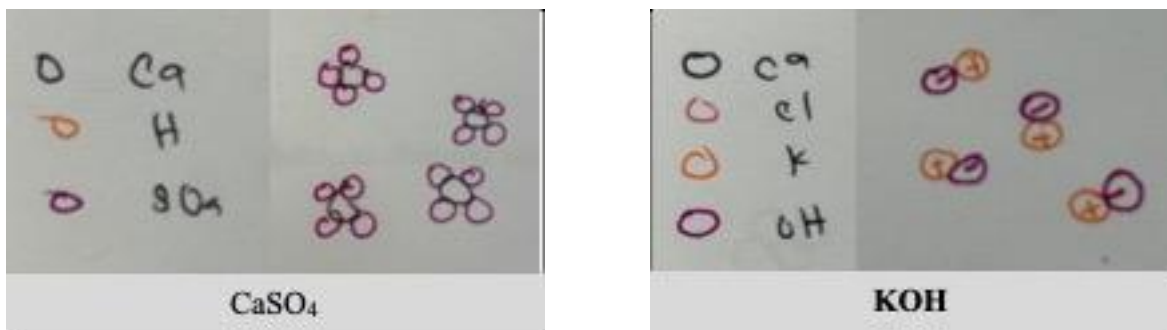
Drawing reactions became more challenging as the number of ionic species involved increased although the ions were all monatomic. Another notable observation is that the two displacement reactions involved ionic species that combined in a ratio of not 1:1 in their formula unit (unlike for combination reaction where it is 1:1). Single displacement involved Cu^{2+} and Cl^- that combined in a 1:2 ratio to make CuCl_2 . And this is the same for MgCl_2 . Double displacement involved Na^+ and S^{2-} that combined in a 2:1 ratio in Na_2S . It appeared that students also found it more challenging to draw reactions involving monatomic ions that combined in a ratio of 1:2 or 2:1 compared to those that combined in a 1:1 ratio in their formula units.

The transfer test of the teacher-feedback group yielded an unexpected observation. Students produced better drawings of double displacement than single displacement reaction even though double displacement involved greater number of ionic species than single displacement. These displacement reactions involved not only monatomic but also polyatomic ions. An examination of the features of the polyatomic ions involved in the reaction may explain this unexpected observation and this is discussed in the next section.

Drawing chemical reactions involving polyatomic ions depends on the number of atoms that make up the ionic species and charges of the ions

In the transfer test, all four species involved in the double displacement reaction were ionic. These were Ca^{2+} , OH^- and two spectator ions, Cl^- and K^+ . Single displacement involved three ions (i.e., H^+ , Ca^{2+} and SO_4^{2-} , a spectator ion), an atom (i.e., Ca) and a molecule (i.e., H_2). Hence it was expected that students struggled more in drawing the double displacement than single displacement. Yet in the teacher-feedback group drawing double displacement was better than that of single displacement. This unexpected observation may be explained by the features of the polyatomic ions involved in the reaction, i.e., number of constituent atoms and charges of the ions. Figure 21 compares Student 1's drawings of aqueous solutions of CaSO_4 and KOH .

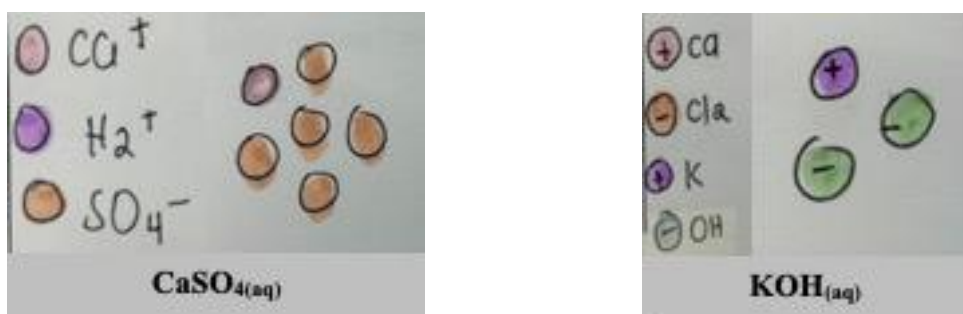
Figure 21 Student 1's Drawings of Aqueous Solution of CaSO_4 and KOH



In Student 1's drawing of CaSO_4 , Ca^{2+} and SO_4^{2-} were incorrectly represented as 'molecules' (did not dissociate into discrete circles) and bear no charges. Also, it seemed that Student 1 thought that the subscript 4 in the formula SO_4 refers to the number of SO_4 'molecules'. This drawing was inaccurate because SO_4 was not a molecule but an ion (i.e., SO_4^{2-}). More so, the subscript 4 refers to the number of oxygen atoms that constitute the polyatomic ion not the number of SO_4^{2-} ions.

In Student 1's drawing of KOH, K^+ and OH^- were incorrectly represented as bonded particles but were accurately shown as ions (with charges). Also, each OH^- ion is accurately shown as one polyatomic unit. It appeared that drawing polyatomic ions with associated subscripts greater than 1 was more challenging than those with associated subscript of just 1. Figure 22 compares another student's (Student 2) drawings of $CaSO_4$ and KOH.

Figure 22 Student 2's Drawings of Aqueous Solution of $CaSO_4$ and KOH



In Student 2's drawings, both $CaSO_4$ and KOH were accurately shown as made up of dissociated ions. Both the monatomic (Ca^{2+} and K^+) and polyatomic ions (SO_4^{2-} and OH^-) were correctly represented as dissociated discrete circles. However, the charges of Ca^{2+} and SO_4^{2-} were incorrectly assigned as 1+ and 1- whereas the charges of K^+ and OH^- were accurately assigned as 1+ and 1-. The student may have learnt of formula writing using *swap and drop* or *crisscross* method (i.e., the magnitude of each of the ion's charges is crossed over to become the subscript of the other), which was part of the topic on writing and naming ionic compounds taught before chemical reactions. Student 2 may have thought that SO_4 had a charge of 1- because in the formula $CaSO_4$, Ca had no subscript written next to it (a subscript of 1 is not usually written) and that Ca had a charge of 1+ because SO_4 had no subscript written next to it. Drawing the polyatomic ion, SO_4^{2-} with an overall charge of 2- was found to be more challenging than the polyatomic ion, OH^- whose overall charge is 1-.

The students appeared to have found it challenging to draw polyatomic ions where the number of constituent atoms (subscripts) and overall charge of the ions are higher than 1.

In summary, the difficulty of drawing chemical reactions depends on the identity of the species involved. Drawing atomic and/or molecular species was found to be less challenging than drawing ions. This finding is consistent with Cheng (2018), Cheng and Gilbert (2017), and Nyachwaya et al. (2011) who argued that students experience less challenges in using the particle model (spatial rearrangement only) in explaining chemical reactions compared to the atomic model (spatial rearrangement and interaction of electrons). Additionally, these previous studies and my current study utilised particulate drawings to examine students' submicroscopic understanding of reactions. However, pictures (Cheng, 2018; Cheng and Gilbert, 2017) and/or equations (as part of a diagnostic tool) (Nyachwaya et al., 2011) were used to prompt students to draw their submicroscopic understanding of reactions. My study offers additional evidence through drawings prompted by practical work and supported with either teacher-feedback or peer-feedback. This additional evidence further strengthens the finding on students' difficulty in drawing ions. Students still faced more difficulties in drawing ions than drawing atoms and molecules even after gaining macroscopic experience of the reaction, receiving support in the form of feedback and given immediate opportunity to revise one's work based on the feedback.

In examining students' particulate drawings of reactions, my study offers a way to advance how these drawings are assessed. Other studies on students' drawings of reactions assessed them generally as spatial rearrangement of the reactant particles to form products (Chang et al., 2014; Davidowitz et al., 2010; Kern et al., 2010; Ryan and Stieff, 2019; Yarroch, 1985). The interaction of the electrons and transformation from ions to atoms/molecules were not usually considered and vice versa (except in Cheng, 2018, and Cheng and Gilbert, 2017). An example was the reaction between hydrochloric acid and solid

calcium carbonate used in the study of Chang et al. (2014). The reaction: $\text{HCl}_{(\text{aq})} + \text{CaCO}_{3(\text{s})} \rightarrow \text{CaCl}_{2(\text{aq})} + \text{H}_2\text{O}_{(\text{l})} + \text{CO}_{2(\text{g})}$ involved both ionic (H^+ , Cl^- , Ca^{2+} and CO_3^{2-}) and molecular species (H_2O and CO_2). Yet in the study it was expected that students show in their (computer) drawings only the correct molecular structures of the reactants and products before, during, and after rearrangement. A limitation of Chang et al. (2014) is that formation of ions was not considered in the drawings. My study has shown how both spatial rearrangement and transformation of particle identities (from atoms and/or molecules to ions and vice versa) can be considered by examining changes in the spatial and visual elements of the particulate drawings respectively. Although my study was conducted using freehand drawings, the examination of the changes in the visual and spatial elements can be readily applied to computer drawings. It is important that changes in particle identities are considered in drawing since it was demonstrated by my study that the difficulty of drawing reactions depends on the identity of the particles involved as atoms, molecules, and ions.

Further, the findings of my study determined the challenges students faced in drawing different types of ionic species, e.g., monatomic, and polyatomic. In drawing reactions involving monatomic ions, the difficulty increases as the number of ions increases and when the ratio of the ions in the formula unit is not 1:1. In the recall test drawing the displacement reactions that involved more ionic species whose combining ratio in their formula units were 1:2 or 2:1 was more challenging than the combination reaction. Nonetheless drawing reactions involving polyatomic ions was more challenging than those that involved monatomic ions. Nyachwaya et al. (2011) has identified polyatomic ions as one of the difficulties in drawing reactions. However, there are different types of polyatomic ions. They have different features like the number of constituent atoms within the ion and the overall charge of the ion. Such features of polyatomic ions were not considered in the work of

Nyachwaya et al. (2011). My study has shown that the difficulty in drawing polyatomic ions varies depending on these features.

In the transfer test drawing the combustion of beryllium (combination) was less challenging than the two displacement reactions because the combustion of beryllium involves not only a smaller number of ionic species but also that they are both monatomic (i.e., Be^{2+} and O^{2-}) that combined in a 1:1 ratio in their formula unit BeO . The single displacement was found to be more challenging than the double displacement even though the former involved more ionic species than the latter. This is because the single displacement reaction includes the polyatomic ion SO_4^{2-} which was found to be more challenging for students to draw than the polyatomic OH^- in the double displacement reaction. The polyatomic ion, SO_4^{2-} , has a subscript of more than 1 for one of its constituent atoms (O has a subscript of 4). And the polyatomic ion has also an overall charge of more than 1 (it is 2-). Students were prone to represent ions as either “+” and “-” irrespective of the magnitude of the charges of the ions (e.g., they tended to assign “-” to sulfate ions). A possible reason for this may be related to the scientific convention that the symbol “+” may refer to a positive charge or positive charges and “-” may refer to one or more negative charges. Such convention is encountered by students not only on the topic of ionic bonding but also in other science topics like electricity (e.g., movement of negative charges). Students may have not realized that writing just “+” and/or “-” does not only mean positive and/or negative charged ions but a charge magnitude of 1 (one electron is lost and/or gained by the atom).

The finding of my study on how the difficulty of drawing reactions involving ions vary based on its features advances the two models of reaction proposed by Cheng (2018), and Cheng and Gilbert (2017). My study offers new insights into the layers of complexity of the atomic model of chemical reaction. The features of the ionic species involved in the

reaction influence students' difficulty in visualizing chemical reactions using the atomic model. Figure 23 summarizes how the difficulties of drawing reactions that involved ions vary depending on the features of the ionic species. Darker shade boxes present features that students found more challenging than those in the lighter shade boxes.

Figure 23 *Difficulties in Drawing Reactions Involving Ions Depends on the Features of the Ionic Species*

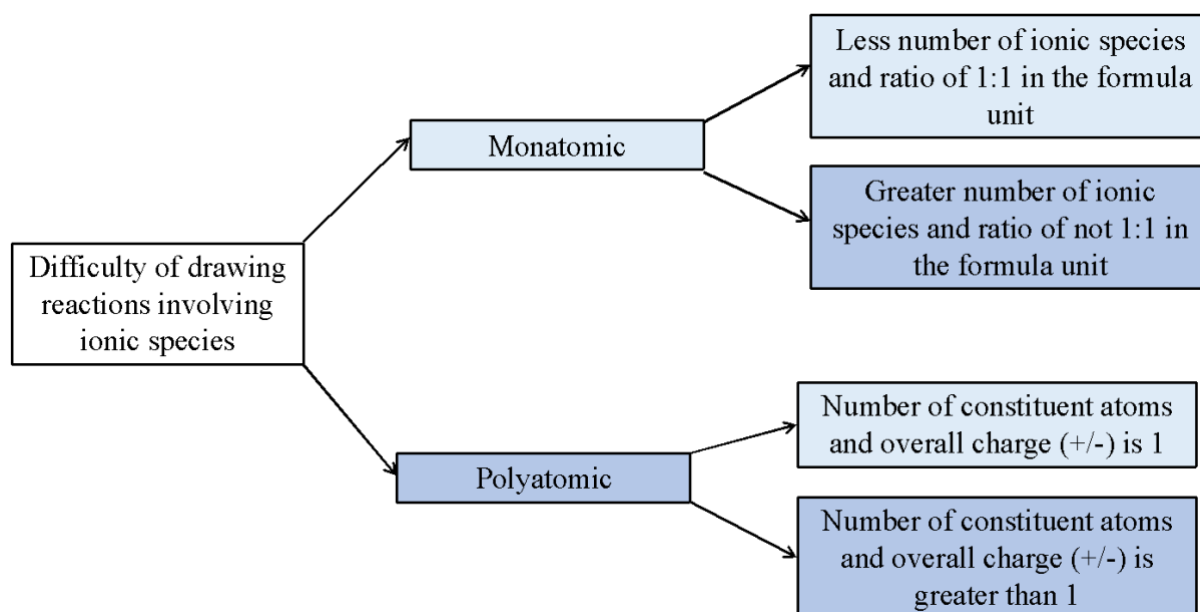


Figure 23 shows that it was more challenging to draw reactions involving polyatomic than monatomic ions. For reactions involving monatomic ions it was more challenging to draw those that involved a greater number of ionic species and whose combining ratio is not 1:1. For reactions involving polyatomic ions drawing those that have a number of constituent atoms and overall charge (+ or -) of more than 1 was more challenging than those whose number of constituent atoms and overall charge (+ or -) is 1.

In re-implementing the intervention suggested improvements could be considered. To support students in drawing the single displacement reaction (reaction of solid calcium and

sulfuric acid) by making it less challenging, the sulfuric acid may be replaced by hydrochloric acid (HCl). The HCl molecule dissociates into two discrete ionic species just like H_2SO_4 (H^+ and SO_4^{2-}) but only involves monatomic ions, H^+ and Cl^- with a charge of 1+ and 1-, and whose combining ratio is 1:1. Also the reactions utilized in the intervention could be sequenced in order of increasing complexity, i.e., by varying the features of the ionic species progressively. Drawing may start from a reaction that involved atomic and molecular species, e.g., $\text{C}_{(\text{s})} + 2\text{H}_{2(\text{g})} \rightarrow \text{CH}_{4(\text{g})}$. After which ion formation and particle identity transformation can be introduced. It may begin from a reaction that involved a fewer number of monatomic ions, e.g., $2\text{K}_{(\text{s})} + \text{I}_{2(\text{g})} \rightarrow 2\text{KI}_{(\text{s})}$ with associated subscripts of 1 in their formula unit. Consequently, the number of ionic species can be increased with associated subscripts of 1 (in effect, ionic charges of 1+ and 1-), e.g., $2\text{Li}_{(\text{s})} + 2\text{HCl}_{(\text{aq})} \rightarrow 2\text{LiCl}_{(\text{aq})} + \text{H}_{2(\text{g})}$ and then with associated subscripts of more than 1 (with ionic charges of not 1+ or 1-), e.g., $\text{Mg}_{(\text{s})} + \text{CuCl}_{2(\text{aq})} \rightarrow \text{Cu}_{(\text{s})} + \text{MgCl}_{2(\text{aq})}$. Finally, reactions involving polyatomic ions may be used starting from those with subscripts of only 1 within the polyatomic unit, e.g., $\text{NaOH}_{(\text{aq})} + \text{HCl}_{(\text{aq})} \rightarrow \text{NaCl}_{(\text{aq})} + \text{H}_2\text{O}_{(\text{l})}$ and then with subscripts of more than 1, e.g., $\text{Ca}_{(\text{s})} + \text{H}_2\text{SO}_{4(\text{aq})} \rightarrow \text{CaSO}_{4(\text{aq})} + \text{H}_{2(\text{g})}$.

Findings of this study also showed that decomposition is less challenging. The data from the single and double displacement reactions suggest that decomposition was easier not because of its reaction type but because the two displacement reactions involved more ions, both monatomic and polyatomic ions. It is also therefore envisaged that not all decomposition reactions are equally 'easy'. The thermal decomposition of solid calcium carbonate (one of the oldest reactions known) produces solid calcium oxide (use for cement making) and carbon dioxide gas represented by the equation: $\text{CaCO}_{3(\text{s})} + \text{heat} \rightarrow \text{CaO}_{(\text{s})} + \text{CO}_{2(\text{g})}$. This decomposition reaction is unlikely to be that simple for students to draw because it involved

ions one of which is a polyatomic ion, CO_3^{2-} whose number of constituent atoms and overall charge is not 1. Another example is using sodium hydrogen carbonate (baking soda) as a rising agent for baking. Solid sodium hydrogen carbonate when heated produces solid sodium carbonate, carbon dioxide gas (use for 'rising' baked products) and liquid water: $2\text{NaHCO}_{3(s)} \rightarrow \text{Na}_2\text{CO}_{3(s)} + \text{CO}_{2(g)} + \text{H}_2\text{O}_{(l)}$. Drawing $\text{Na}_2\text{CO}_{3(s)}$ involved the polyatomic ion, CO_3^{2-} whereas drawing solid NaHCO_3 involved the polyatomic ion HCO_3^- , which has a constituent atom whose number is more than one (three O atoms).

Chapter 8 Efficacy of Teacher-Feedback and Peer-Feedback in Supporting Drawing to Learn Chemical Reactions

This chapter presents the discussion of the efficacy of the two feedback sources in supporting drawing to learn the different reaction types. The chapter starts with a synthesis of notable quantitative findings from Chapters 5 and 6. After which, how the efficacy of the two feedback sources varies depending on the difficulty of drawing the reactions including its spatial elements is discussed.

8.1 Notable Quantitative Findings

This section synthesizes the results of the comparison between the quality of drawings from the two feedback groups across the types of chemical reactions during and a month after the intervention. Both groups exhibited similar order of difficulty in drawing the types of chemical reactions (see Chapter 7) yet overall teacher-feedback group produced better drawings than peer-feedback group as shown in Table 47. In the table, >> represents higher adjusted mean score percentage and is statistically significant. The qualitative description of the effect size is also given in Table 47 (for the summary of effect size values, see Tables 35, 40 and 45).

Table 47 *Comparison Between the Quality of Drawings in the Two Feedback Groups**Overtime*

Types of chemical reactions	During the intervention	After the intervention	
		Recall	Transfer
Combination	TF >> PF remarkable	TF >> PF remarkable	TF >> PF remarkable
Decomposition	TF >> PF modest	TF = PF	TF = PF
Single displacement	TF >> PF remarkable	TF >> PF modest	TF >> PF remarkable
Double displacement	TF >> PF remarkable	TF >> PF modest	TF >> PF remarkable
Overall	TF >> PF remarkable	TF >> PF remarkable	TF >> PF remarkable

The following are notable observations from Table 47:

Both feedback groups produced similar quality of drawings of the reaction not involving ions

Teacher-feedback group's drawings of decomposition reaction during the intervention were better than the peer-feedback group, yet the difference was only modest. One month after the intervention, both groups produced comparable quality of drawings in the recall and transfer tests.

Teacher-feedback group produced better drawings than peer-feedback group of the reactions involving ions

Teacher-feedback group's drawings of combination and displacement reactions during the intervention were remarkably better than peer-feedback group. A month after the intervention, there was a decrease in the differences between the two groups for the two displacement reactions, whereas the difference for combination remained remarkable. In the transfer test for combination and displacement reactions, the teacher-feedback group still

produced remarkably better drawings than the peer-feedback group. Teacher-feedback was a better form of support than peer-feedback in drawing reactions that were more challenging. Notably, identity of the particles involved in the reactions has been found to influence the difficulty of drawing the reactions (see summary of notable results 1). Since particle identity determines difficulty of drawing reactions, the groups' adjusted mean scores in the 'identity of the chemical species' criterion were compared as shown in Table 48. The identity of the particles is a visual element which was one of the two components where the drawings were assessed. The identity of the particles can be ions, atoms and/or molecules. In Table 48, the symbols '>' and '<' represent differences in adjusted mean score percentage but were not statistically significant.

Table 48 *Quality of Drawings in the 'Identity of the Chemical Species' Criterion for the Two Feedback Groups*

Types of chemical reactions	During the intervention	After the intervention	
		Recall	Transfer
Combination	TF >> PF	TF < PF	TF = PF
	4.83 >> 3.51 remarkable	3.64 < 3.76	3.71 = 3.71
Decomposition	TF > PF	TF > PF	TF < PF
	10.7 > 10.1	8.96 > 8.82	8.27 < 8.98
Single displacement	TF >> PF	TF >> PF	TF >> PF
	5.27 >> 2.54 remarkable	3.28 >> 2.56 modest	5.59 >> 2.94 remarkable
Double displacement	TF >> PF	TF >> PF	TF >> PF
	9.41 >> 5.00 remarkable	5.24 >> 3.91 modest	3.66 >> 1.11 modest

The following are notable observations from Table 48. They are like those from Table 47, which suggest that the pattern of differences between the two groups' drawings may be attributed primarily to the differences in drawing the identity of the particles:

Both feedback groups had comparable drawings of the identity of the particles of the reaction not involving ions

Both group's scores in drawing the identity of the particles of decomposition reaction were not statistically different during the intervention and in the post-tests – for both the recall and transfer tests.

Teacher-feedback group generally produced better drawings of the identity of the particles of the reactions involving ions compared to peer-feedback group

The teacher-feedback group's drawings of the identity of the particles for combination and displacement reactions during the intervention were remarkably better than peer-feedback group but it decreased one month after the intervention. In the recall test, the differences between the groups for the two displacement reactions became modest. The two groups became comparable for combination reaction in both recall and transfer tests. This suggest that the remarkable overall difference between the two feedback groups in the recall and transfer tests for combination reaction (see Table 47) may not be because of the identity of the particles (visual element) but the spatial elements (second component where drawings were assessed). Similar interpretation can be said about the transfer test for the double displacement reaction. In Table 47, the overall difference between the two groups was remarkable. But in drawing the identity of the particles it was only modest (see Table 48). Hence, the overall difference may be brought about by the difference in drawing the spatial elements. This can be demonstrated by comparing the groups' adjusted mean scores in the spatial elements (i.e., arrangement and distance among the particles). Table 49 presents the comparison of the two feedback groups' drawings of the spatial elements of the four types of chemical reactions during and a month after the intervention.

Table 49 *The Two Feedback Groups' Quality of Drawing the Spatial Elements*

Types of chemical reactions	During the intervention	After the intervention	
		Recall	Transfer
Combination	TF > PF	TF >> PF	TF >> PF
	9.90 > 8.94	11.1 >> 8.66 remarkable	10.3 >> 7.75 remarkable
Decomposition	TF > PF	TF > PF	TF >> PF
	10.5 > 9.31	9.36 > 8.39	9.48 >> 7.86 modest
Single displacement	TF >> PF	TF >> PF	TF >> PF
	16.4 >> 14.2 remarkable	11.5 >> 8.77 modest	10.1 >> 6.61 remarkable
Double displacement	TF >> PF	TF >> PF	TF >> PF
	14.7 >> 12.9 modest	13.3 >> 11.6 modest	13.3 >> 10.2 remarkable

The following are observations from Table 49 on the drawings of the spatial elements:

Both feedback groups generally had similar quality of drawing the spatial elements of the reaction not involving ions

Both groups' drawings of the spatial elements of decomposition reaction during the intervention and in the recall test were comparable. In the transfer test, there was only a modest difference.

Teacher-feedback group generally produced drawings of the spatial elements of the reactions involving ions better than peer-feedback group

For combination reaction, teacher-feedback group had remarkably better drawings in the recall and transfer tests compared to peer-feedback group. Though, during the intervention, both feedback groups had comparable drawings.

For single displacement reaction teacher-feedback group produced drawings that were remarkably better during the intervention and in the transfer test and modestly better in the recall test compared to the peer-feedback group. Also, the pattern between the two groups'

drawings of the spatial elements was the same with the identity of the chemical species (see Table 48) and the overall drawing (see Table 47).

For double displacement, teacher-feedback group's drawings were modestly better during the intervention and in the recall test, and remarkably better in the transfer test compared to peer-feedback group.

8.2 The Efficacy of the Two Feedback Sources Varies Depending on the Difficulty of Drawing the Reactions Including Its Spatial Elements

Overall comparison of the drawings between the two feedback groups suggests that teacher-feedback generally provided better support than peer-feedback for drawing reactions. Teacher-feedback was particularly useful for drawing the more challenging reactions, i.e., combination and displacement. These reactions involved particle changes from atoms and/or molecules to ions (and vice versa). Teacher-feedback supported students better than peer-feedback in drawing the identity of the particles particularly ions. Figures 24 and 25 present sample drawings of the combustion of magnesium (combination reaction) from the two feedback groups.

Figure 24 *Teacher-Feedback Student's Drawing of Combination Reaction*

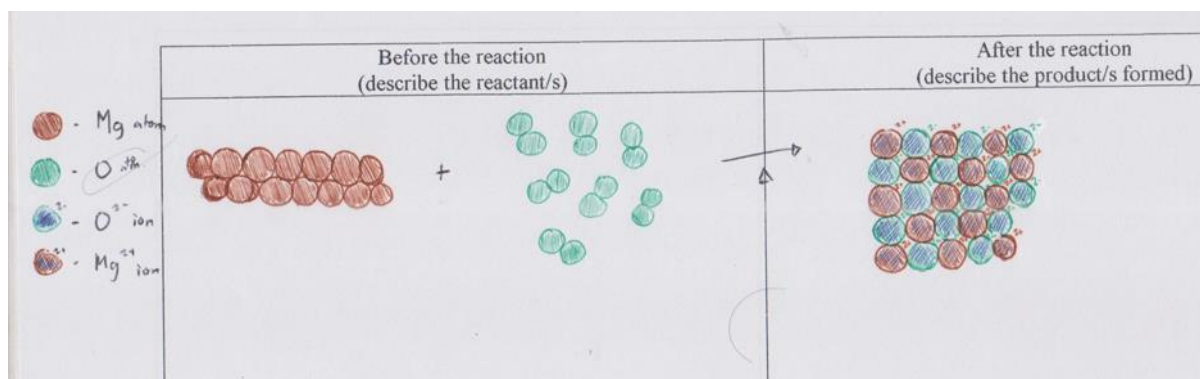
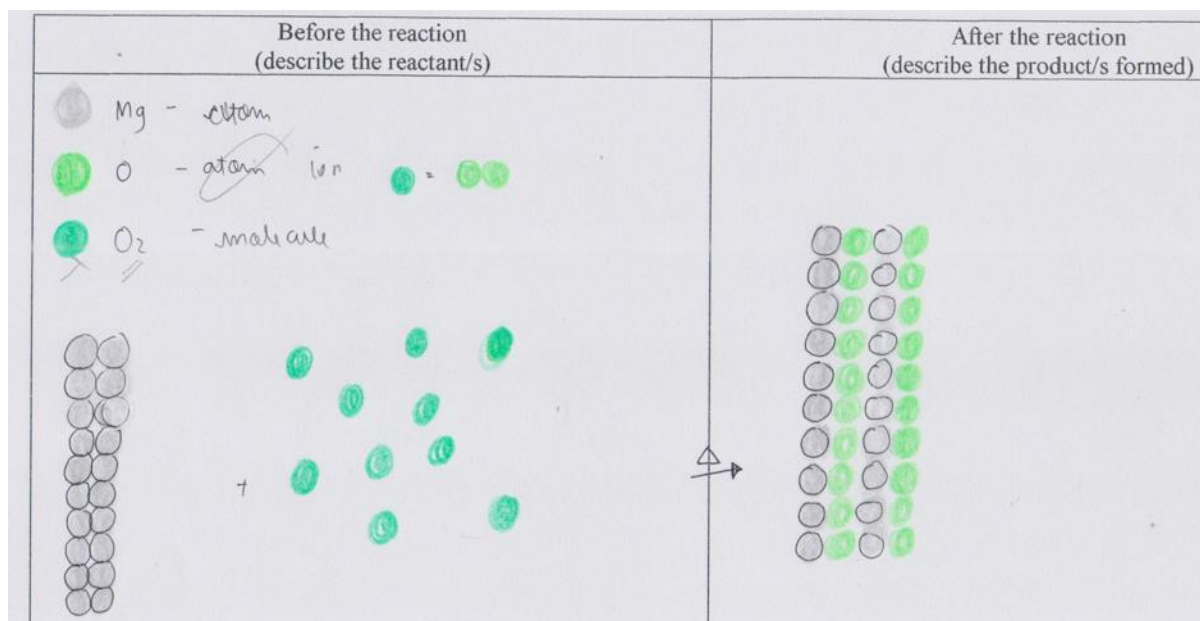


Figure 25 *Peer-Feedback Student's Drawing of Combination Reaction*

The student from the teacher-feedback group (Figure 24) accurately drew the identity of the particles of magnesium as atoms, oxygen as diatomic molecules and magnesium oxide as ions (Mg^{2+} and O^{2-}) whereas the student from peer-feedback group (Figure 25) drew oxygen and magnesium oxide as atoms. Additionally, the reactions in which teacher-feedback group produced better drawings of the identity of the chemical species were the same reactions that teacher-feedback students had better overall drawings compared to peer-feedback students. These reactions were combination and both displacement during the intervention; single displacement for both post-tests; and double displacement for the recall test. The teacher being a domain expert (Tsivitanidou et al., 2011) supported drawing the challenging reactions, a task that involved more conceptual ideas. This finding on the efficacy of teacher-feedback rather than peer-feedback in supporting drawing to learn agrees with previous studies that found teacher-feedback was more useful than peer-feedback in supporting writing to learn (Paulus, 1999; Ruegg, 2015; Tajik et al., 2016; and Yang et al., 2006).

Peer-feedback was equally useful as teacher-feedback in drawing the least challenging reaction, i.e., decomposition. This reaction involved atomic and/or molecular species, which did not undergo particle identity transformation (atoms and molecules remain as atoms and molecules). Peer-feedback supported students like teacher-feedback in drawing these neutral particles. Figures 26 and 27 show sample drawings of decomposition of hydrogen peroxide from the two groups.

Figure 26 Teacher-Feedback Student's Drawing of Decomposition Reaction

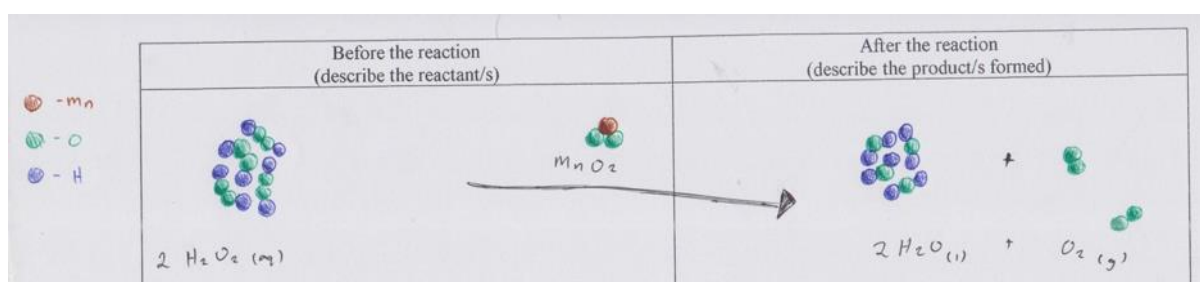
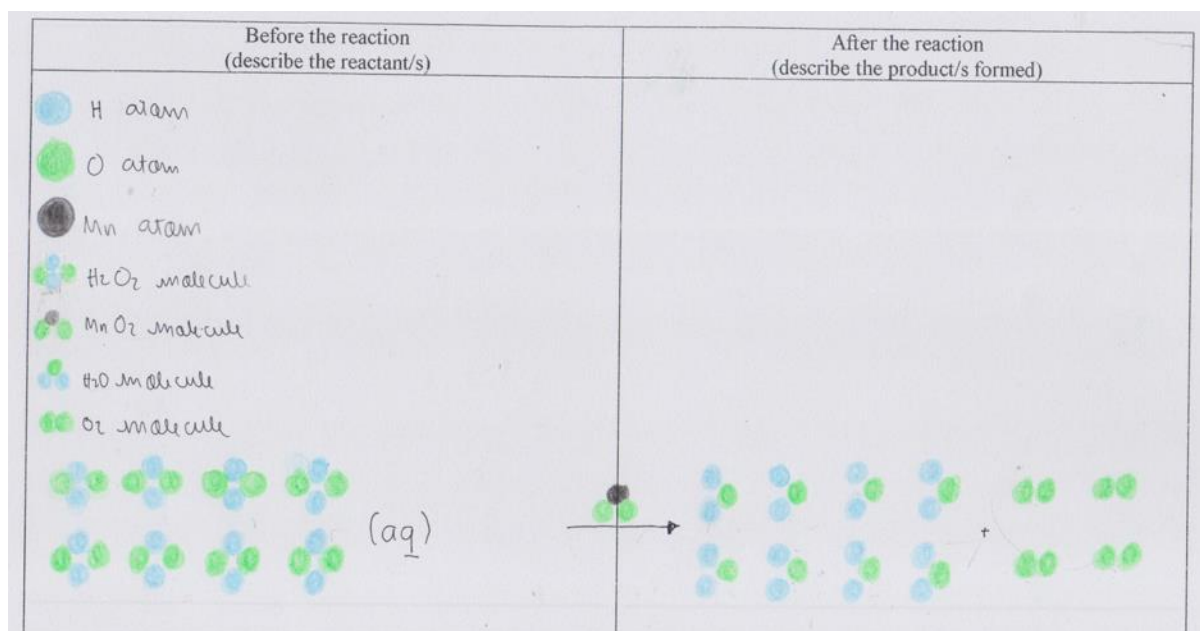


Figure 27 Peer-Feedback Student's Drawing of Decomposition Reaction



In both Figures 26 and 27, both feedback groups accurately drew hydrogen peroxide, water, and oxygen as molecules. The peer-feedback students produced an overall quality of drawing the decomposition reaction comparable to the teacher-feedback students because

they were supported in drawing the identity of the particles. This finding is affirmed by the similar pattern of no statistical differences observed between the two groups in their post-tests for the overall quality of drawing the decomposition reaction (see Table 47) and in the *identity of the chemical species* criterion (see Table 48). The students demonstrated their ability to readily use the particle model of reaction (i.e., draw atoms and molecules as particle identities that rearranged to form the product) than the atomic model (Cheng, 2018; Cheng & Gilbert, 2017). This outcome on the efficacy of peer-feedback in supporting drawing the easier reaction echoes the findings that peer-feedback can be of high quality and can be comparable, if not better, to teacher-feedback (Cho et al., 2008; Cho & MacArthur, 2010; Yangin Eksi, 2012; and Gielen et al., 2010b); although, domain knowledge does influence the quality of feedback (Hovardas et al., 2014; Strijbos & Sluijsmans, 2010).

For the *spatial elements*, teacher-feedback still supported students to draw the arrangement and distances among particles based on their phases better than peer-feedback. For reactions that involved solid substances, the teacher-feedback group generally produced better drawings of the spatial elements compared to the peer-feedback group. Teacher-feedback students' drawings of the combination reaction in the recall and transfer tests, and the two displacement reactions during the intervention and in both post-tests were statistically better than peer-feedback group. Both two reactions involved metallic and ionic solid substances. To illustrate the comparison between the two groups' drawings of a reaction involving solids, Figures 28 and 29 present sample drawings of the combustion of magnesium (combination reaction) in the recall test.

Figure 28 Teacher-Feedback Student's Drawing of Combination Reaction in the Recall Test

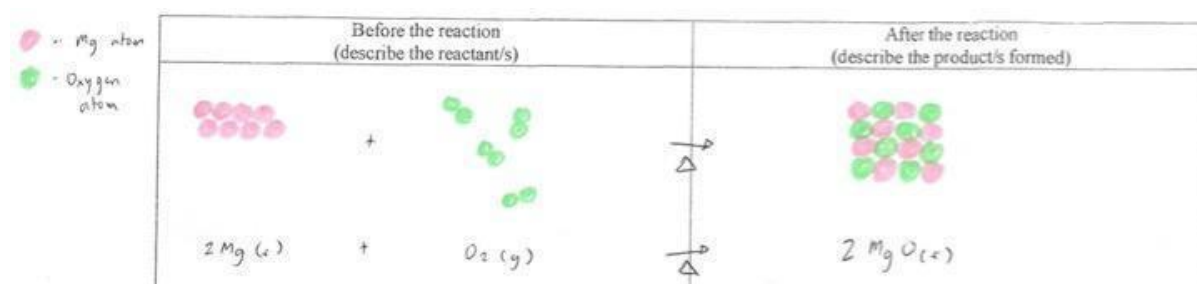


Figure 29 Peer-Feedback Student's Drawing of Combination Reaction in the Recall Test

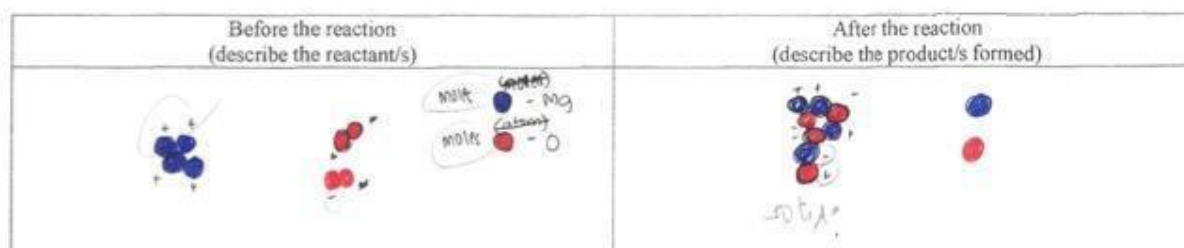


Figure 28 shows that the student from the teacher-feedback group accurately drew the arrangement and distances of the particles of the metallic solid (i.e., magnesium) and ionic solid (i.e., magnesium oxide). Both solid particles were drawn as close to each other. Metallic solid particles were drawn as arranged regularly. The ionic solid particles of magnesium oxide were drawn as regularly alternating Mg and O. Figure 29 shows that the peer-feedback group drew the arrangement of the solid particles as arranged irregularly for both the metallic and ionic solids. Also, the ionic solid appeared as non-crystalline, i.e., arranged as irregularly alternating Mg^+ and O^- .

Both feedback groups, however, found drawing reactions that involved fluid substances (liquids and gases) to be challenging. Drawings of the spatial elements of the decomposition reaction during the intervention and in the post-tests were comparable for both groups. Students from the two feedback groups appeared to have struggled in drawing and distinguishing between the distances of liquid and gaseous particles more than their arrangement as illustrated in Figures 30 and 31 (decomposition of hydrogen peroxide).

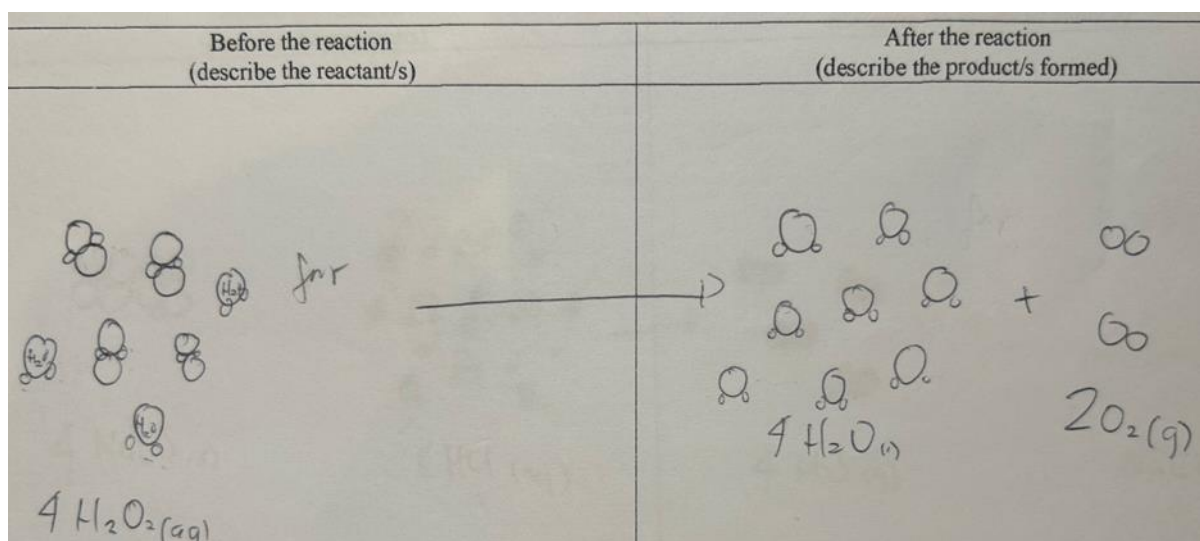
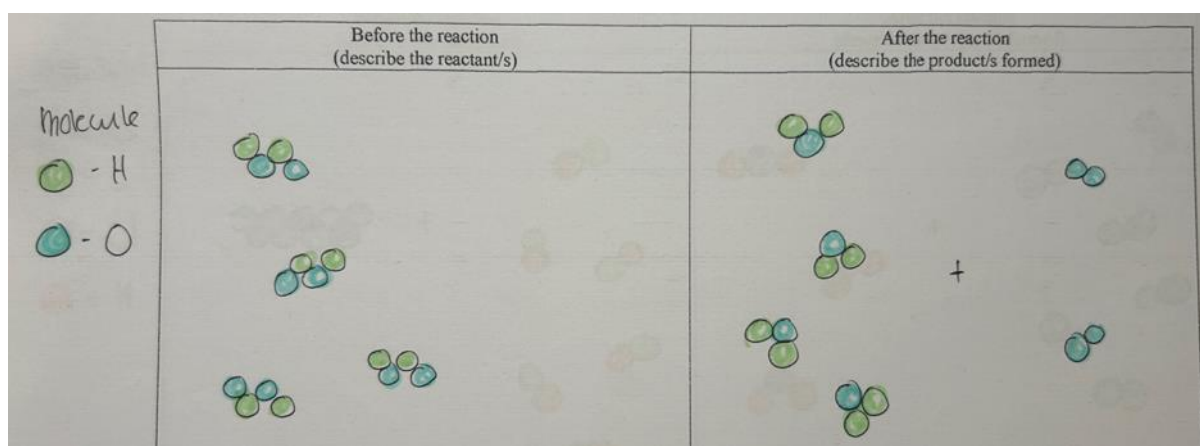
Figure 30 Teacher-Feedback Student's Drawing of Decomposition Reaction in the Recall Test**Figure 31** Peer-Feedback Student's Drawing of Decomposition Reaction in the Recall Test

Figure 30 shows that the teacher-feedback student accurately drew the arrangement of both liquid (H_2O_2 and H_2O) and gaseous (O_2) substances as randomly scattered. However, the distance among particles were both like that of the gas, i.e., with the same wide empty spaces. Figure 31 presents a peer-feedback student who drew both liquid (H_2O_2 and H_2O) substances as scattered randomly but with even wider empty spaces between them. In both drawings, there was no distinction between the liquid and the gaseous substances.

Better drawings of the two *spatial elements* (i.e., arrangement and distance between particles) contributed to better overall drawings of the reactions. In the transfer test, the teacher-feedback group's drawing of the double displacement reaction was remarkably better

for the *spatial elements* (Table 49) and modestly better for the *identity of the particles* (Table 48) than peer-feedback group. And this led the teacher-feedback group's remarkable overall drawing of the double displacement compared to the peer-feedback group (Table 47). Additionally, in both recall and transfer tests, teacher-feedback group's overall drawings of combination reaction were remarkably better than peer-feedback (Table 47). This is likely because of the remarkable difference in drawing the *spatial elements* (Table 49). After all the groups' drawing of the *identity of the chemical species* were comparable (Table 48).

This finding on how spatial elements contribute to the quality of students' drawings of reactions reinforces the importance of assessing it and not just the visual elements (i.e., identity and conservation of the particles). Previous studies of students' drawings of reactions left out these spatial elements (Cheng, 2018; Cheng and Gilbert, 2017; Kern et al., 2010; Nyachwaya et al., 2011). Additionally spatial elements were assessed as 'position' of the particles (Ryan and Stieff, 2019) and not as two distinct components: arrangement and distance between particles. As observed in my study, students accurately understood the arrangement of particles of liquid and gaseous substances but struggled to differentiate the particle distances between them. So, assessing spatial elements ambiguously as 'position' cannot reveal such distinction in students' understanding.

In sum, teacher-feedback generally supported students in drawing both the *visual (identity of the particles)* and *spatial elements* better than peer-feedback. This finding offers another evidence to support previous studies that identified the usefulness of teacher-feedback in supporting learning. My study offers drawing to learn as a learning context differing to writing to learn (Paulus, 1999; Ruegg, 2015; Tajik et al., 2016; Yang et al., 2006) to demonstrate the efficacy of teacher-feedback as a feedback source. My study also offers new evidence using drawing as artefacts of learning to exemplify how learning context influence the usefulness of the two feedback sources. The finding that teacher-feedback was

more useful than peer-feedback in supporting drawing to learn is consistent with previous studies that found Asian students viewed teacher-feedback as more valuable than student-feedback (Paulus, 1999; Ruegg, 2015; Tajik et al., 2016; Yang et al., 2006) because they were more used to teacher-dominated instruction and have high regard for the teacher's authority and expertise. Filipino students are used to teacher-centred approaches (Del Valle, 2020, 2022 & 2023) and peer-feedback as a teaching-learning activity was not a typical class activity due to large class sizes (Class Size and Conditions Act, 2022). A teacher's authority and expertise in the classroom is culturally valued (Del Valle, 2020, 2022 & 2023). In drawing the challenging reactions, there may have been lack of peer acceptance and trust of peer-feedback because the students are aware that their peers, just like them, lack the needed content knowledge (Gielen et al., 2010a). Therefore, students tend to trust their teacher's competence (Killingback et al., 2020) better than their peers in judging their work.

The usefulness of teacher-feedback in drawing ions as particle identity, however, appeared to wane overtime as the reaction became complex. The results show that the difference between the two groups' drawing of the *identity of the chemical species* in the two displacement reactions diminished from remarkable during the intervention to modest in the recall test (see Table 48). The quality of teacher-feedback groups' drawings of the *identity of the chemical species* dropped more than the peer-feedback group. Consequently, the same pattern for the overall quality of drawings was observed (see Table 47).

In implementing feedback on drawing to learn chemical reactions especially when using peer-feedback, it is an important consideration that students' conceptual knowledge of the identity of the particles (visual element) and spatial elements (i.e., arrangement and distances among particles) are available to them. My study has elucidated that these elements of drawing influenced the efficacy of the two feedback sources. Another important consideration when implementing feedback on drawing is to allow more time for developing

students' trust and acceptance of their feedback provider; particularly if students are not used to the feedback source. The intervention provided two practice sessions for receiving both feedback sources before assessing drawings. These two sessions may not have been enough for the students to develop full confidence towards their peers as feedback providers. These students have been used to the teacher as the prime assessor in the classroom over the years. An examination of the features of teacher-feedback and peer-feedback can provide more insights onto how and why the two feedback sources supported drawing chemical reactions differently. Chapters 9 and 10 present these features of the two feedback sources.

Chapter 9 Teacher-Feedback and Peer-Feedback on a Chemical Reaction Involving Identity Transformation

This chapter presents the results of the qualitative analysis of the feedback generated by the teacher and peers on students' drawings of the combination reaction during the intervention. This presentation of results answers the third research question for a chemical reaction involving identity transformation: *What are the features of feedback that are valuable for supporting drawing to learn chemical reactions?* Chapter 10 presents the results that answers the third research question for a chemical reaction not involving identity transformation.

This chapter begins with a summary of the quantitative results on the drawings of the combination reaction during the intervention. Then, the quantity and quality of teacher-feedback and peer-feedback in each of the four *feedback focus* categories are discussed: (1) visual-spatial elements of the drawing, (2) verbal linkages with the drawing, (3) triplet relationship and (4) prerequisite chemistry knowledge.

9.1 Quantitative Analysis of the Drawings of the Combination Reaction

Quantitative analysis (see Chapter 5 Teacher-feedback and peer-feedback groups' drawings during the intervention) of the drawings of the combustion of magnesium, a combination reaction involving identity transformation from reactants to product (atoms to ions) revealed that:

1. teacher-feedback group scored significantly higher than the peer-feedback group with large effect sizes;
2. teacher-feedback students had the lowest quality of drawings;
3. the quality of drawings of peer-feedback students for this chemical reaction was comparable with both single and double displacement reactions. The quality of drawings of these three chemical reactions were lower than decomposition reaction.

Quantitative and qualitative analyses of the *foci* and *moves* of teacher-feedback during the whole-class presentation and that of peer-feedback during the in-group discussion may offer explanations for these quantitative results. The following section reports on the quantitative and qualitative analyses of the *feedback focus* on the ‘visual-spatial elements of the drawing’ category.

9.2 Feedback on Visual-Spatial Elements of the Drawing

Table 50 presents the frequency of episodes for each *feedback focus* in the teacher-feedback and peer-feedback groups for the combination reaction in the feedback on visual-spatial elements of the drawing.

Table 50 *Frequency of Episodes for Each Feedback Focus in the Teacher-Feedback and Peer-Feedback Groups in the ‘Visual-Spatial Elements of the Drawing’ Category for the Combination Reaction*

<i>Feedback focus</i>	Teacher-feedback group	Peer-feedback group
Overall quality of the drawing	3	9
Distance between particles	22	5
Arrangement of particles	35	9
Conservation of particles	50	29
Identity of the chemical species	105	21
Total	215	73

The teacher-feedback group had almost three times more total feedback episodes than the peer-feedback group (215 vs. 73). Both groups had the same total lesson time and each team-assessee (from the teacher-feedback group), or student-assessee (from the peer-feedback group) was allotted the same amount of time to receive feedback (5 minutes). However, the two groups did not have the same total amount of time to give/receive feedback (see Section 3.4.2). Students in the teacher-feedback group had more total time to receive feedback than those in the peer-feedback group (40 vs. 30 minutes).

For the ‘visual-spatial elements of the drawing’ category, the teacher generated roughly five feedback episodes in a minute (215 feedback episodes/40 minutes) while peers generated roughly two feedback episodes in a minute (73 feedback episodes/30 minutes). Therefore, with an addition of 10 minutes to make the total time to give/receive feedback identical for both groups, peers would have generated roughly 20 more feedback episodes. The addition of 20 feedback episodes could have resulted to a total of 93 feedback episodes for the peer-feedback group. These 93 total feedback episodes from the peers are still lower than 215 total feedback episodes from the teacher.

The greater number of feedback episodes from the teacher may have provided more feedback ideas about the visual-spatial elements of the drawings. For example, on the identity of the particles of the chemical species the teacher has provided feedback ideas about the identity and properties of the particles of the product. The teacher also recognised identity transformation (atoms to ions), but peers did not (see Section 9.2.1)

Furthermore, in Table 50 for the teacher-feedback group, the two most frequent *feedback foci* were on the identity of the chemical species followed by conservation of particles. The *foci* of teacher-feedback were about accurately representing the identity of the particles of the chemical species involved in the chemical reaction as ions, atoms or molecules, and the Law of Conservation of Mass (or Particles). For *feedback moves*, Figures 32 and 33 show that ‘Identifying an idea’ was the most frequently used *feedback move* by the teacher for the four *feedback foci*: Identity of the chemical species, conservation of particles, arrangement of particles and distance between particles. Then, for the overall quality of the drawing, the teacher utilised the ‘Finding out more about an idea’ *move*.

Figure 32 Comparison Between the Teacher-Feedback and Peer-Feedback Moves Used for the Visual Elements of the Drawing of the Combination Reaction

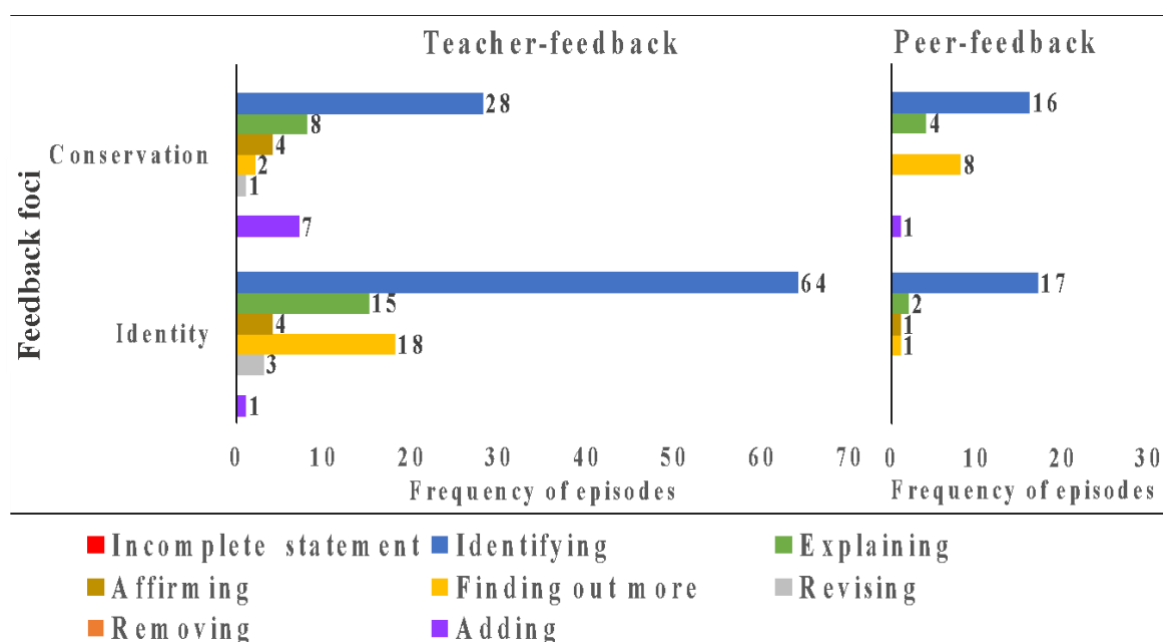
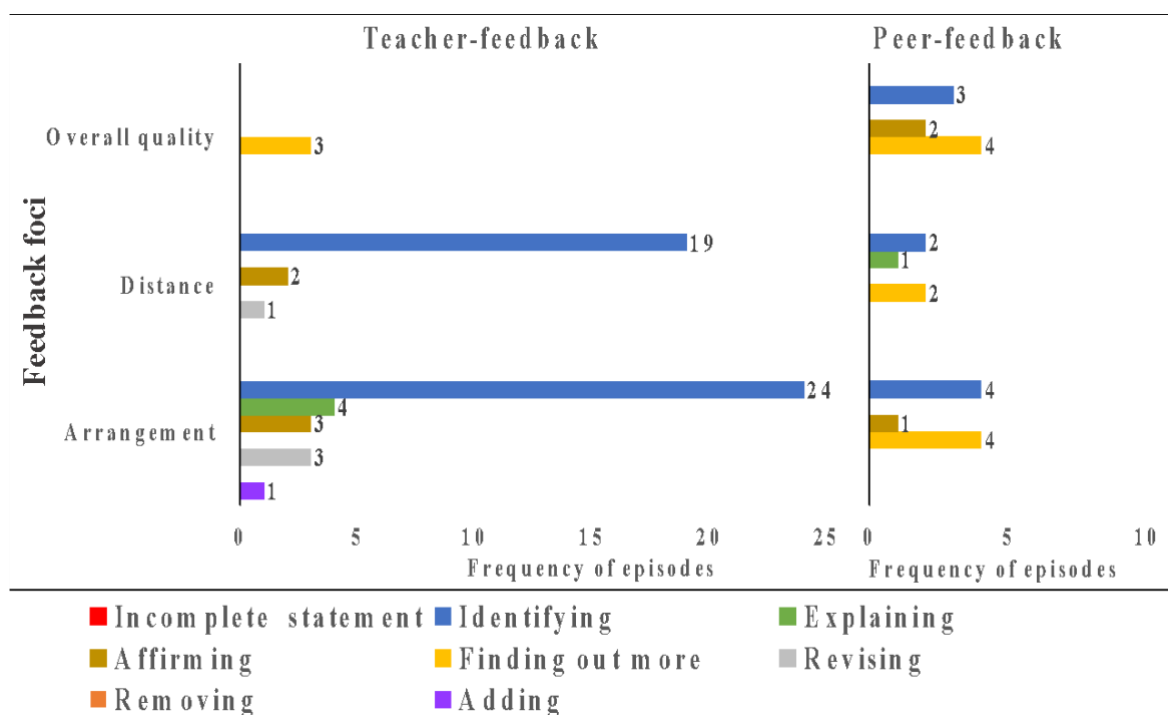


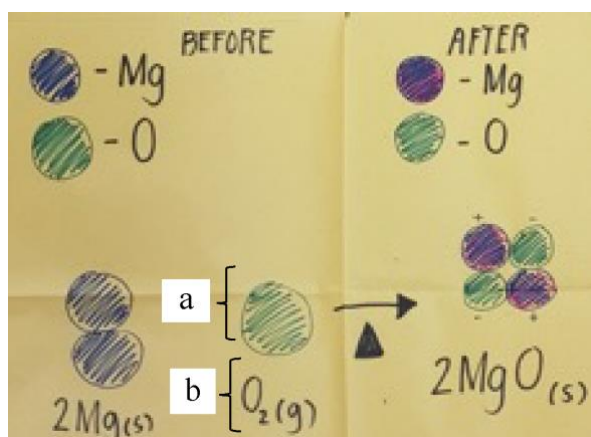
Figure 33 Comparison Between the Teacher-Feedback and Peer-Feedback Moves Used for the Spatial Elements and Overall Quality of the Drawing of the Combination Reaction



Figures 32 and 33 also show that the teacher had used ‘Explaining an idea’ *move* for the identity of the chemical species, conservation of particles, and arrangement of particles. When the teacher gave feedback on the drawings across the three *feedback foci*: Identity of the chemical species, conservation of particles, and arrangement of particles, explanations were provided to substantiate feedback ideas. An example of this ‘Explaining an idea’ *move* is the teacher’s feedback on the identity of the chemical species in the drawing of Group 6 (see Figure 34). For distance between particles, the teacher identified feedback ideas but did not provide explanations to substantiate them. An example of this ‘Identifying an idea’ *move* is the teacher’s feedback on the drawing of Group 1 (see Figure 51). In the overall quality of the drawing, the teacher delivered feedback by posing questions that sought further information. An example of this ‘Finding out more about an idea’ *move* is the teacher’s feedback on the drawing of Group 4 (see Figure 54).

And for oxygen, that's not oxygen (pointing at ‘a’). That's only O, oxygen atom (pointing at ‘a’). You had another O circle to bond with O. There should be two green circles. Two green circles for O₂. Because that is only O (pointing at ‘a’). That is 2 O (pointing at ‘b’). (Teacher-feedback on Group 6)

Figure 34 Group 6’s Drawing



In the peer-feedback group, as shown in Table 50, the two most frequent *feedback foci* were on the conservation of particles followed by the identity of the chemical species. The *foci* of peer-feedback were on accurately applying the Law of Conservation of Mass (or Particles) and accurately representing the identity of the particles of the chemical species involved in the chemical reaction as ions, atoms, or molecules. For *feedback moves*, as shown in Figures 32 and 33, in all *feedback foci* of the ‘visual-spatial elements of the drawing’ category (i.e., conservation of particles, identity of the chemical species, arrangement of particles, and distance between particles including overall quality of the drawing), peers mostly used ‘Identifying an idea’ and ‘Finding out more about an idea’. Yet for the conservation of particles, identity of the chemical species, and distance between particles peers also used the ‘Explaining an idea’ *move*. Peers gave explanations to substantiate their feedback ideas about the conservation of particles, identity of the chemical species, and distance between particles. For the arrangement of particles and overall quality of the drawing, peers did not provide explanations and often posed questions that sought further information.

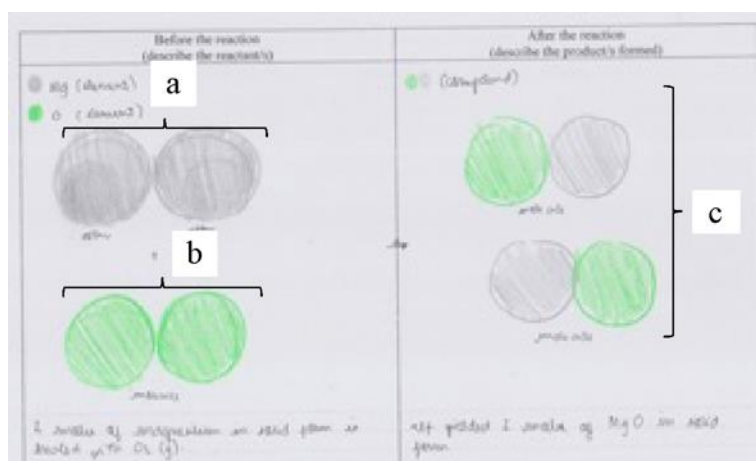
Both the teacher and peers had the same two *feedback foci*, which were the visual elements of the drawings: the identity of the particles of the chemical species and conservation of particles. For *feedback focus* on the identity of the particles of the chemical species, both teacher and peers frequently utilized the same *feedback move*, which was the identification of ideas. Both the teacher and peers gave explanations to substantiate their feedback ideas about the visual elements of the drawings. The teacher however provided explanations more frequently than the peers.

The two *feedback moves*, i.e., identifying and explaining are illustrated in the sample feedback from the teacher and a student’s peer. On the teacher’s feedback for the drawing of Group 6 (Figure 34), the teacher explained the difference between an oxygen atom and an

oxygen molecule and how it should be drawn. On a peer's feedback for the drawing of Student 1 (Figure 35), the peer identified which are atoms, molecules, and the product in the drawing. However, no explanation was mentioned by the peer about the product.

For atom, you just have one (pointing at 'a'). For molecule, you have two; like O_2 (pointing at 'b'). Then, if the product will change, it will be like this (pointing at 'c').
(Peer-feedback on Student 1)

Figure 35 Student 1's Drawing

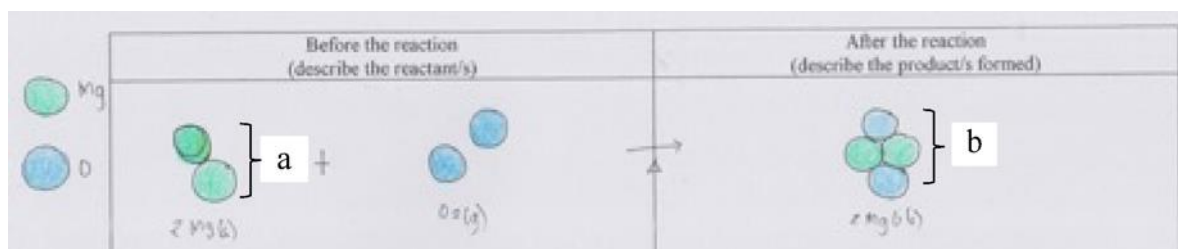


For *feedback focus* on the conservation of particles, both the teacher and peers explained their ideas about the Law of Conservation of Mass (or Particles). Yet peers also asked questions that sought further ideas. The following are sample feedback on the conservation of particles: For teacher's feedback on the drawing of Group 5 (Figure 36) the teacher explained to students how to show the conservation of particles in their drawings. For peer's feedback on the drawing of Student 5 (Figure 37), the peer posed a question about how to balance the number of particles of the chemical species in the drawing.

You can have any number of magnesium atoms (pointing at ‘a’). But make sure that the number of circles you drew on your sketch matched the number of circles in the product (pointing at ‘b’) and that is conservation of atom.

(Teacher-feedback on Group 5)

Figure 36 *Group 5's Drawing*



Student 4: How do you balance?

Student 5: Why is this still not balanced?

(Peer-feedback on Student 5)

Figure 37 *Student 5's Drawing*

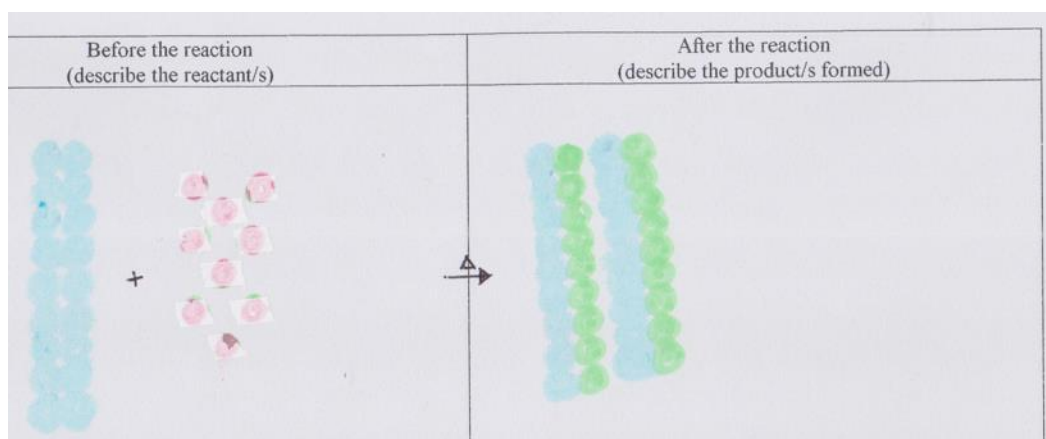


Table 51 presents a summary of the results on the general quantitative and qualitative differences between teacher-feedback and peer-feedback in the ‘visual-spatial elements of the drawing’ category for the combination reaction.

Table 51 *General Quantitative and Qualitative Differences Between Teacher-Feedback and Peer-Feedback in the ‘Visual-Spatial Elements of the Drawing’ Focus Category for the Combination Reaction*

Teacher-feedback	Peer-feedback
<i>Visual-spatial elements of the drawing</i>	
(a) Generated more total feedback episodes (215 episodes) than the students’ peers	(a) Generated 73 total feedback episodes
(b) <i>Feedback foci</i> concentrated on the two visual elements of the drawing: the identity of the chemical species and conservation of particles	(b) <i>Feedback foci</i> concentrated on the same two visual elements of the drawing
(c) Often utilised ‘identifying and explaining ideas’ as <i>feedback moves</i>	(c) Often utilised ‘identifying and finding out more about ideas’ as <i>feedback moves</i>

The following sections discuss specifically how the quality of feedback differs for the teacher-feedback and peer-feedback groups in each of the five *feedback foci* in the ‘visual-spatial elements of the drawing’ category: (a) identity of the chemical species, (b) conservation of particles, (c) arrangement of particles, (d) distance between particles, and (e) overall quality of the drawing. The quotes and exchanges of feedback that were used here are those that illustrate the most frequently occurring feedback ideas in the two groups. This does not mean that these were the only feedback ideas generated by either the teacher or the peers. These quotes and exchanges of feedback were used to highlight the similarities and differences between the quality of feedback of the two groups.

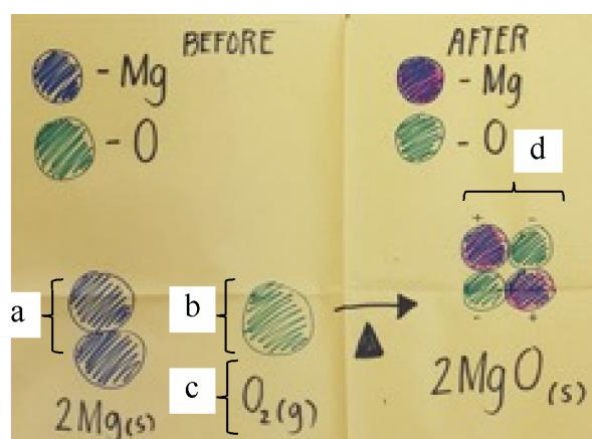
9.2.1 Identity of the Chemical Species

For feedback on the identity of the chemical species, the teacher accurately identified particles of the reactants as ‘atoms’ and ‘molecules’, and the product as ‘ions’. The accuracy of the identity of particles that the teacher expected from students is illustrated in the following teacher’s feedback on the drawing of Group 6 (Figure 38):

In the reactants, magnesium and oxygen are in the form of atoms (pointing at 'a') and molecules (pointing at 'b') (respectively). But in the product, they are ions (pointing at 'd').

(Teacher-feedback on Group 6)

Figure 38 Group 6's Drawing



Additionally, the teacher did not only point out the identity of the particles per se but also explained how that identity should be represented in the drawing. For example, after pointing out that oxygen is a 'molecule', the teacher explained that to draw an oxygen molecule there should be two circles bonded together. Each circle representing an oxygen atom. This is illustrated in the following teacher's feedback on the same drawing of Group 6 (Figure 38):

And for oxygen, that's not oxygen (pointing at 'b'). That's only O, oxygen atom (pointing at 'b'). You had another O circle to bond with O. There should be two green circles. Two green circles for O₂ (molecule). Because that is only O (pointing at 'b'). That is 2 O (pointing at 'c').

(Teacher-feedback on Group 6)

The teacher also indicated that there was a transformation in the identity from atoms (and molecules) to ions. And the teacher instructed students to explicitly show it in their drawings via colour changes. This is illustrated in the following teacher's feedback on the same drawing of Group 6 (Figure 38):

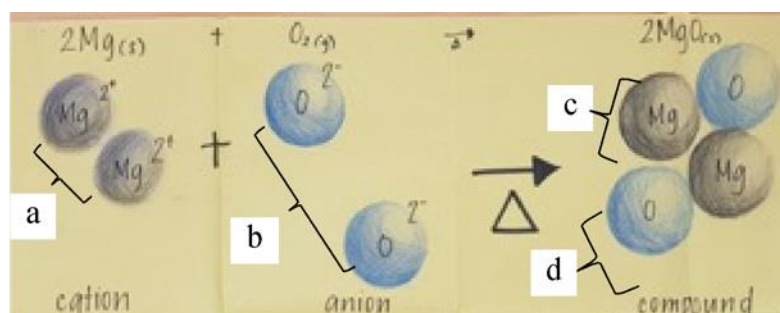
You can change the colour so that you can see the transformation of the atom (pointing at 'a' and 'b') to ion (pointing at 'd').

(Teacher-feedback on Group 6)

For teacher's feedback on the drawing of Group 6 (Figure 38), the teacher did not only point out the concept of identity transformation. He also identified how it can be drawn. However, there were times that the teacher was implicit in identifying the identity of the particles. Consider the following teacher's feedback on the drawing of Group 2 (Figure 39):

The *magnesium* there (pointing at 'a') in its neutral state has no charge. The *magnesium ribbon*, the *magnesium metal*, the *magnesium* there has no charge first. It is neutral.

(Teacher-feedback on Group 2)

Figure 39 Group 2's Drawing

The teacher indicated that ‘magnesium’ on the reactant side should be in a neutral state and therefore should have no charge. The teacher commented not only on the identity of the particles but also on the property of the particles, i.e., charges. Nonetheless in this teacher-feedback on the drawing of Group 2 (Figure 39), the teacher did not explicitly mention the identity of ‘magnesium’ as magnesium atoms. It was implied that the teacher was referring to the submicroscopic level since the ‘magnesium’ being addressed to be neutral were drawn as ions (see ‘a’). There was a shift in the teacher’s descriptive level, i.e., from ‘magnesium (atoms)’ (submicroscopic level) to magnesium ribbon, magnesium metal (macroscopic level) back to ‘magnesium (atoms)’ (submicroscopic level). After the teacher indicated that ‘magnesium (atoms)’ has no charge and is neutral, the teacher proceeded by stating that ‘magnesium ribbon’, ‘magnesium metal’ then back to magnesium (atoms)’ has no charge and is neutral.

Additionally, the teacher explained identity transformation from the reactants to the product at the submicroscopic level by identifying the properties of the particles. The exact identities of the particles (as atoms and ions) were implicit. This is illustrated in the following teacher’s feedback still on the same drawing of Group 2 (Figure 39):

When the final reaction with oxygen, when it finally reacts with oxygen (pointing at 'b'), that is the only time that magnesium (pointing at 'a') will give away its two valence electrons to oxygen (pointing at 'b'); acquiring two positive charges as you had there (pointing at 'c'). And oxygen getting the two electrons from magnesium will get a two negative charge (pointing at 'd').

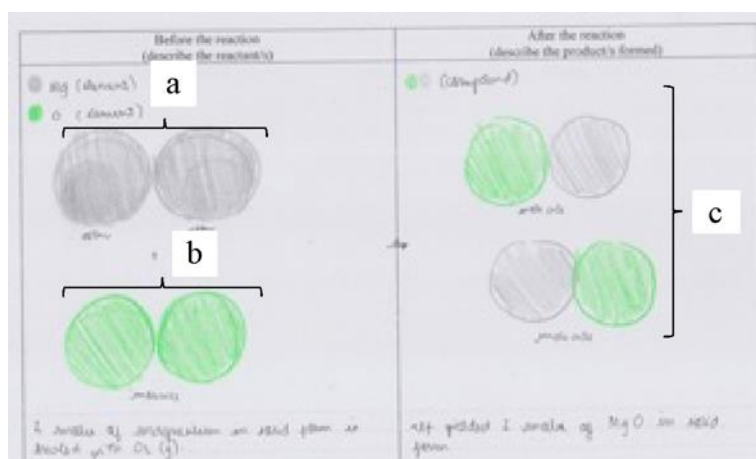
(Teacher-feedback on Group 2)

For teacher's feedback on the same drawing of Group 2 (Figure 39) about 'magnesium' giving away two valence electrons (acquiring 2+ charge) and 'oxygen' getting those two valence electrons (acquiring 2- charge) the teacher explained the interaction of the valence electrons.

On peer-feedback, a student's peer pointed out 'atoms' and 'molecules' as accurate identities of the reactants. These identities were shown as labels of the chemical species in the drawing of Student 1 (see Figure 40). However, the peer did not identify the product as 'ions'. The peer mentioned 'change', but it did not refer to changes in the identity because the peer affirmed that the product was made up of 'molecules'. In effect, the peer did not recognise identity transformation. Moreover, the peer explicitly identified the identity of the particles of the reactants, but not their property, i.e., atoms and molecules are particles that do not bear charges. The identity and property of the product were also not identified, i.e., ions bear charges (Mg^{2+} and O^{2-}). This is illustrated in the following peer's feedback on the drawing of Student 1 (Figure 40):

For atom, you just have one (pointing at 'a'). For molecule, you have two; like O_2 (pointing at 'b'). Then, if the product will change, it will be like this (pointing at 'c').

(Peer-feedback on Student 1)

Figure 40 *Student 1's Drawing*

In terms of recognising the identity of the product, the teacher generated 43 feedback episodes (or roughly 41% of the 105 total feedback episodes) on the ‘identity of the chemical species’ (in Table 50); such feedback mentioned ‘ions’ or at least implied that the product, magnesium oxide is made up of ions. On the other hand, among all 21 total peer-feedback episodes on the ‘identity of the chemical species’, peers never mentioned ‘ions’ as the product. Students in the teacher-feedback group were better supported to represent accurately the identities and properties of both reactants (Mg atoms and O₂ molecules) and product (Mg²⁺ and O²⁻ ions) in their drawings. Students in the peer-feedback group were supported to accurately represent the identities of the reactants being atoms and molecules but not the product as ions nor the properties of the particles of all the chemical species.

For *feedback moves*, Figure 32 shows that there was no difference in the most frequently used *move* of both groups, which was the identification of ideas. Also, both the teacher and students’ peers provided explanations to substantiate their feedback ideas. For the frequency of feedback episodes, the teacher generated five times more total feedback episodes than the peers about the identity of the chemical species (105 vs. 21, see Table 50). This greater number of feedback episodes may have strengthened for the teacher-feedback

group those ideas on identity (and properties) of the particles of the chemical species particularly on the product being ‘ions’.

Table 52 presents a summary of the results on the quantitative and qualitative differences between teacher-feedback and peer-feedback *focus* on ‘identity of the chemical species’ for the combination reaction.

Table 52 *Quantitative and Qualitative Differences Between Teacher-Feedback and Peer-Feedback Focus on ‘Identity of the Chemical Species’ for the Combination Reaction*

Teacher-feedback	Peer-feedback
<i>Identity of the chemical species</i>	
(a) 41% of the total feedback episodes described the product (magnesium oxide) as ions	(a) Did not generate any feedback episode about ‘ions’
(b) Often utilised the ‘Identifying an idea’ move. Also utilised the ‘Explaining an idea’ move to substantiate feedback ideas	(b) Often utilised the ‘Identifying an idea’ move. Also utilised the ‘Explaining an idea’ move to substantiate feedback ideas
(c) Explained the identities and properties of particles of the reactants (Mg atoms and O ₂ molecules have no charges) and product (MgO made up of Mg ²⁺ and O ²⁻ ions) including how such identities can be drawn	(c) Pointed out the identities of the reactants but not the product. Also, the properties of the particles of both the reactants and product were not identified.
(d) Explained identity transformation (i.e., from atoms and molecules into ions) by looking at the chemical behaviour (transfer of valence electrons) of the chemical species	(d) Did not mention ‘identity transformation’

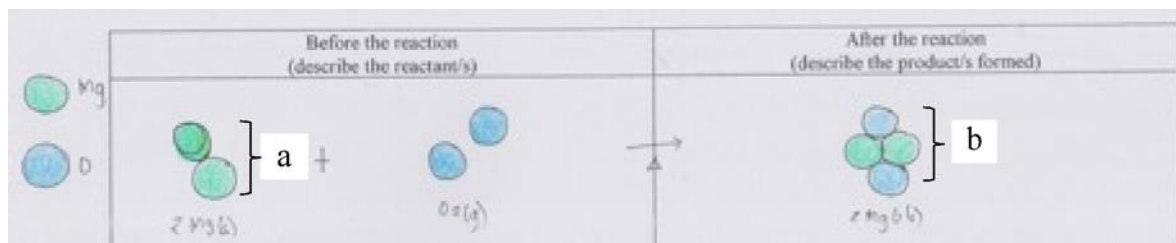
9.2.2 Conservation of Particles

For conservation of particles, the teacher explained how the number of particles of each chemical species would contribute to showing the Law of Conservation of Mass (or Particles) in the drawing. This is illustrated in the following teacher's feedback on the drawing of Group 5 (Figure 41). In the feedback, the teacher looked at the number of magnesium atoms and affirmed the drawing.

You can have any number of magnesium atoms (pointing at 'a'). But make sure that the number of circles you drew on your sketch matched the number of circles in the product (pointing at 'b') and that is conservation of atom.

(Teacher-feedback on Group 5)

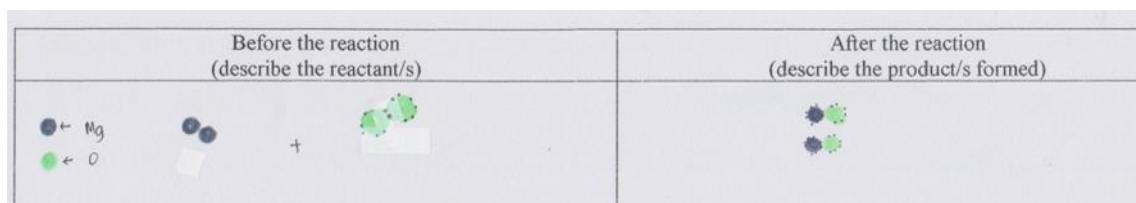
Figure 41 *Group 5's Drawing*



A peer, through his/her feedback, appeared to demonstrate an understanding of the general idea of the Law of Conservation of Mass (or Particles). This is illustrated in the following peer's feedback on the drawing of Student 4 (Figure 42):

You can put as many as you desire (number of particles). It's just that it should be balanced.

(Peer-feedback on Student 4)

Figure 42 *Student 4's Drawing*

In the preceding peer's feedback on the drawing of Student 4 (Figure 42), the peer identified how the Law of Conservation of Mass (or Particles) can be applied in the drawing. However, the exchanges between peers on their feedback on the drawing of Student 6 (Figure 43) suggest students' uncertainty in showing particle conservation. Initially students appeared to know the general idea of mass (or particle) conservation. But as the conversation progressed, it became apparent that they were uncertain on how exactly to show it in their drawings; particularly when asked to draw many particles.

Student 4: Is 'molecule' the same as 'mole'? Or not?

Student 1: No.

Student 6: Here, I should get only five (pointing at 'b')? Then here, I have 10 (pointing at 'd') but should only be five?

Student 1: There should be 10 of this (pointing at 'a'). Ten of this (pointing at 'c'). Five of this (pointing at 'b'). Ten of this (pointing at 'd').

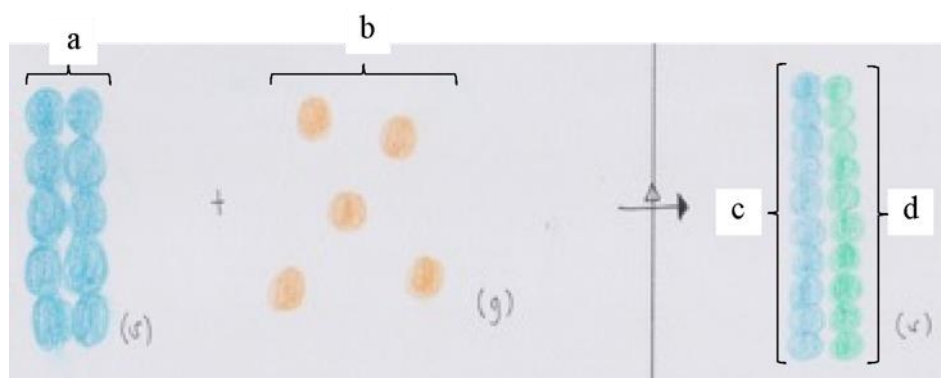
Student 4: Should this be 10 (pointing at 'a')? Here, there should be 10 of this * (pointing at 'd').

Student 1: Yes. Do you think we are doing it correctly?

Student 4: I do not know.

(Peer-feedback on Student 6)

*Incomprehensible

Figure 43 Student 6's Drawing

In the exchanges between peers while giving feedback on the drawing of Student 6 (Figure 43), Student 4 asked whether a molecule is the same as a mole. Student 1 simply answered that no, they are not the same without giving an explanation to substantiate the answer. Further into the conversation, peers repeatedly posed questions about the number of particles of each chemical species. Yet posing questions as a *feedback move* did not lead to the accurate representation of the conservation of particles. The magnesium atoms in the reactant and product sides were equal but oxygen atoms were not. It might be that the five oxygen particles on the reactant side referred to five oxygen (O_2) molecules (10 oxygen atoms). That is why Student 6 had 10 oxygen atoms on the product side. However, this cannot be checked because the students did not explain this during the exchange. Students only identified that there should be five oxygen particles on the reactant side (see 'b' in the drawing) and 10 oxygen particles on the product side (see 'd' in the drawing). Even so, that oxygen 'molecules' in the reactant side (see 'b' in the drawing) was not drawn as diatomic but as discrete atoms.

It was evident that feedback from the teacher explained how to show the Law of Conservation of Mass (or Particles) in the drawings. Peers as assessors appeared to know the general idea posited by the Law of Conservation of Mass (or Particles). Students were able to explain it to their peers. Yet when drawing it students appeared to be uncertain. There were

gaps in their understanding of how to precisely show particle conservation. These gaps were evident when peers posed questions that sought further information. Those questions did not lead to the accurate application of the idea of particle conservation.

For the number of feedback episodes, the teacher generated more than the peers (50 vs. 29; see Table 50). Having a greater number of feedback episodes may have increased the frequency for teacher-feedback students to encounter the feedback ideas on conservation of particles. In effect, such frequent encounter may have contributed to reinforcing a better understanding of the feedback ideas on the conservation of particles. 54% of teacher-feedback students and 49% of peer-feedback students were able to accurately show the conservation of both magnesium and oxygen particles in their drawings. Then 17% of teacher-feedback students while 29% of peer-feedback students were not able to completely show the conservation of particles in their drawings. Table 53 presents a summary of the results on the quantitative and qualitative differences between teacher-feedback and peer-feedback *focus* on ‘conservation of particles’ for the combination reaction.

Table 53 *Quantitative and Qualitative Differences Between Teacher-Feedback and Peer-Feedback Focus on ‘Conservation of Particles’ for the Combination Reaction*

Teacher-feedback	Peer-feedback
<i>Conservation of particles</i>	
(a) Generated more feedback episodes (50 episodes) than the students’ peers	(a) Generated 29 feedback episodes
(b) Compared to peer-feedback, more students (54%) accurately showed the conservation of both magnesium and oxygen particles in their drawings while fewer students (17%) incompletely showed the conservation of particles in their drawings	(b) Compared to teacher-feedback, fewer students (49%) accurately showed the conservation of both magnesium and oxygen particles in their drawings while more students (29%) incompletely showed the conservation of particles in their drawings
(c) Often utilised ‘Identifying and explaining ideas’ as <i>feedback moves</i> .	(c) Often utilised ‘Identifying and finding out more about an idea’ as <i>feedback moves</i> .

Explanations were used to substantiate feedback ideas.	However, posing questions did not lead to the accurate representation of the conservation of particles.
(d) Explained the proper application of the Law of Conservation of Mass (or Particles)	(d) Students' peers were less certain about how to accurately represent the Law of Conservation of Mass (or Particles)

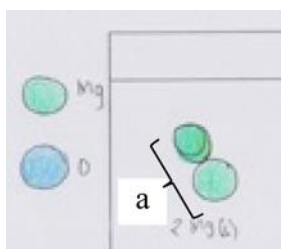
9.2.3 Arrangement of Particles

For the arrangement of particles, the teacher pointed out that magnesium should be represented as a solid made up of not only two atoms but many atoms bonded together. By drawing only two atoms, magnesium appeared as a diatomic gas molecule. This is illustrated in the following teacher's feedback on the drawing of Group 5 (Figure 44):

Draw the entire solid structure of magnesium (pointing at 'a'). You can draw the entire picture of the atoms bonded together.

(Teacher-feedback on Group 5)

Figure 44 *Group 5's Drawing of Magnesium*

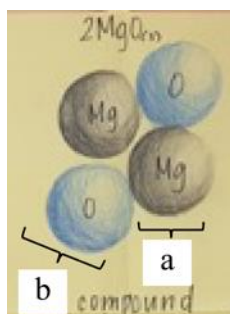


However, the teacher did not explicitly mention that drawing many magnesium atoms bonded together should be shown as stacked above each other in a regular pattern. This would represent magnesium as a metallic crystal. The teacher also gave feedback on the structure of the product, magnesium oxide (MgO). The teacher explained that MgO should be represented as a crystal structure with alternating Mg and O particles. This is illustrated in the following teacher's feedback on the drawings of Groups 2 (Figure 45) and 3 (Figure 46):

Mg (pointing at 'a') should be pictured as surrounded by several O (pointing at 'b'). Then, of course, that is for three-dimensional arrangement. And O (pointing at 'b') is surrounded by Mg (pointing at 'a') as well, in the crystal. So, you are to improve on that.

(Teacher-feedback on Group 2)

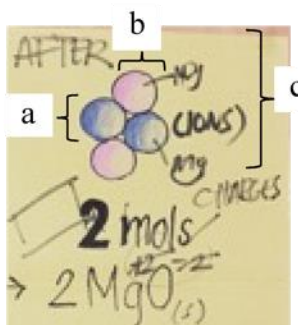
Figure 45 *Group 2's Drawing of Magnesium Oxide*



Know that all those, all those (pointing at 'c') are arranged as I said in the crystal structure. All the positive (pointing at 'a') are surrounded by negative (pointing at 'b'). All negative (pointing at 'b') are surrounded by positive (pointing at 'a'). Of course, that is for three-dimensional arrangement.

(Teacher-feedback on Group 3)

Figure 46 *Group 3's Drawings of Magnesium Oxide*



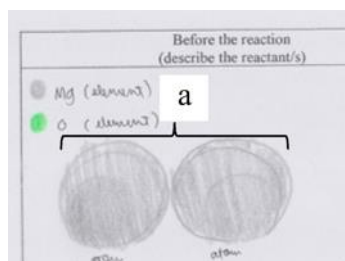
When the teacher gave feedback on particle arrangement of the product (magnesium oxide) instead of using the full names of the particles such as ‘magnesium ions’ or ‘magnesium 2+ ions’, and ‘oxygen ions’ or ‘oxygen 2- ions’ he used a shorthand (i.e., ‘Mg’ and ‘O’ in Group 2, and ‘positive’ and ‘negative’ in Group 3). Hence, there was a shift in the teacher’s descriptive level from submicroscopic level (i.e., ‘magnesium ions’, ‘magnesium 2+ ions’, ‘oxygen ions’, ‘oxygen 2- ions’) to symbolic level (i.e., ‘Mg’, ‘O’, ‘positive’, ‘negative’). Additionally, the teacher was implicit in identifying that magnesium oxide particles should be alternating in a regular pattern to show that it is an ionic crystal.

Peers however did not comment on the ionic crystalline structure of the product (magnesium oxide). There was no feedback episode from the peers about the arrangement of the particles of the product. Instead, feedback from a peer described the reactant (magnesium) as a strip made up of atoms stacked above each other. This is illustrated in the following peer’s feedback on the drawing of Student 1 (Figure 47):

Probably what we should do is to draw a strip made up of two long vertical columns with many atoms (pointing at ‘a’).

(Peer-feedback on Student 1)

Figure 47 *Student 1’s Drawing of Magnesium*

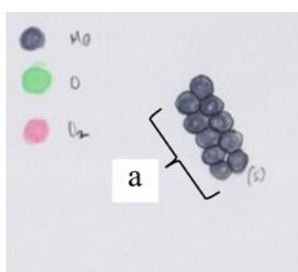


Nevertheless, another peer posed a question that sought confirmation on whether drawing magnesium as a strip made up of atoms stacked above each other was indeed an accurate representation. This is illustrated in the following peer's feedback on the drawing of Student 4 (Figure 48):

Should it be like this (pointing at 'a')? Drawn as a strip?

(Peer-feedback on Student 4)

Figure 48 *Student 4's Drawing of Magnesium*



The peers, just like the teacher, did not mention explicitly that magnesium atoms should be drawn stacked above each other in a regular pattern to represent it as a metallic crystal. Moreover, when asked why magnesium should be drawn as a strip, a peer only suggested that it should be drawn as a strip made up of atoms stacked above each other but did not give an explanation to justify it. This is illustrated in the following exchanges of feedback on the drawing of Student 5 (Figure 49).

Student 1: There. That should be fine (pointing at 'a').

Student 5: Why should it be drawn like this (pointing at 'a')?

Student 4: A strip.

Student 5: How did you do it? Is it like this, downward (pointing at 'a')?

Student 4: Yes.

(Peer-feedback on Student 5)

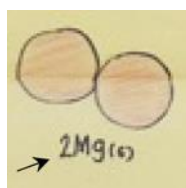
Figure 49 *Student 5's Drawing of Magnesium*



Comparing the foregoing peer-feedback on the drawing of Student 5 (Figure 49) with the subsequent teacher-feedback on the drawing of Group 7 (Figure 50) the teacher did not only identify magnesium as a strip made up of atoms stacked above each other. He also gave an explanation using the concept of the mole to substantiate it.

Now, regarding your (magnesium) particles. So, as I said several times. Magnesium is solid, so you picture that. You think that there only two atoms of magnesium participating. That 2 (pointing at '2') is the mole. Meaning that there are millions of particles involved. But you can have several magnesium atoms in your representation that are closely packed together.

(Teacher-feedback on Group 7)

Figure 50 *Group 7's Drawing of Magnesium*

It appeared that peer-feedback students were less certain about the metallic crystalline structure of magnesium let alone the ionic crystalline structure of magnesium oxide. Peers did not generate any feedback on the arrangement of magnesium oxide which was more complicated than magnesium. Magnesium oxide is made up of two ions, i.e., Mg^{2+} and O^{2-} arranged not only in a regular pattern but also alternating to represent its ionic crystalline structure. Overall feedback episodes from the teacher covered the arrangement of particles of both a reactant (magnesium) and product (magnesium oxide). Feedback episodes from the peers covered only the arrangement of particles of the reactant (magnesium). In effect teacher-feedback students were supported to accurately draw both the structures of the reactant and product. Peer-feedback students were supported only to accurately draw the structure of a reactant.

Quantitatively the teacher generated almost four times more feedback episodes than the peers (35 vs. 9) (see Table 50). Those feedback episodes from the teacher were often delivered by identification of ideas supported with explanations to substantiate those ideas. Feedback episodes from the peers were often delivered by identification of ideas without explanation and by posing questions. The greater number of feedback episodes and the explanations from the teacher might have reinforced better for the teacher-feedback students the feedback ideas on particle arrangement. Table 54 presents a summary of the results on the quantitative and qualitative differences between teacher-feedback and peer-feedback *focus* on ‘arrangement of particles’ for the combination reaction.

Table 54 Quantitative and Qualitative Differences Between Teacher-Feedback and Peer-Feedback Focus on ‘Arrangement of Particles’ for the Combination Reaction

Teacher-feedback	Peer-feedback
<i>Arrangement of particles</i>	
(a) Generated more feedback episodes (35 episodes) than students’ peers	(a) Generated nine feedback episodes
(b) Often used ‘Identifying and explaining ideas’ as <i>feedback moves</i>	(b) Often used ‘Identifying an idea’ and ‘Finding out more about an idea’ as <i>feedback moves</i>
(c) Explained the structures of a reactant (Mg as a metallic crystal) and the product (MgO as an ionic crystal). Chemical symbols and the properties of the particles (i.e., charges as labels for the particles) were used to explain the structure of MgO.	(c) Identified the correct structure of a reactant (Mg) but not the product (MgO)
(d) Was implicit in explaining the arrangement of Mg atoms (regular pattern) and MgO (Mg^{2+} and O^{2-} ions alternating regularly)	(d) Was implicit in identifying the arrangement of Mg atoms (regular pattern)

9.2.4 Distance Between Particles

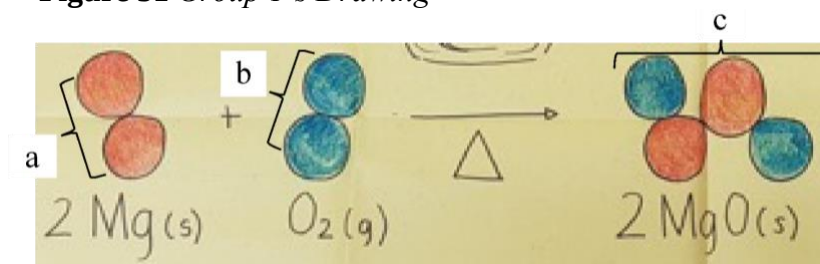
For distance between particles the teacher pointed out how to draw the spaces between particles of both the solid (close and compact) and gaseous (far apart) chemical species. This is illustrated in the following teacher’s feedback on the drawing of Group 1 (Figure 51):

So, you picture magnesium (pointing at ‘a’) as having a close compact structure. Then, oxygen (pointing at ‘b’) is correct. There are two, they are bonded together, and are far apart. Again, gas, far apart. But the atoms should be bonded together to form the O_2 . And

then the magnesium oxide (pointing at 'c') is also correct. But of course, you need some more particles. You need some more particles packed together in the solid structure.

(Teacher-feedback on Group 1)

Figure 51 *Group 1's Drawing*



The teacher added that students should draw more particles to show more precisely the phases of the chemical species while using the correct spaces between the particles.

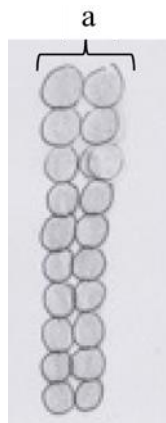
Drawing few particles shows partial understanding. Drawing only two atoms of magnesium may convey that magnesium is a diatomic gas molecule. In the same way drawing only one O_2 molecule cannot show oxygen as a gas with molecules that are widely separated.

Peers, just like the teacher, also pointed out the accurate distance between particles of both the solid (close and compact) and gaseous (far apart) chemical species. This is illustrated in the following peers' feedback on the drawings of Students 1 (Figure 52) and 3 (Figure 53):

This is solid (pointing at 'a'), that is why this is compact.

(Peer-feedback on Student 1)

Figure 52 *Student 1's Drawing of Magnesium*



Student 3: For my work, these are two moles of magnesium (pointing at 'a') and two moles of oxygen (pointing at 'b'). The magnesium is solid, and the oxygen is gas.

Student 5: Why is it like that (pointing at 'b')?

Student 3: They are together.

Student 5: The gas?

Student 3: This is the gas (pointing at 'b'). Oxygen is the gas.

Student 5: Yes, the gas appears to be together.

Student 3: Then, we separate them.

Student 1: They should be together.

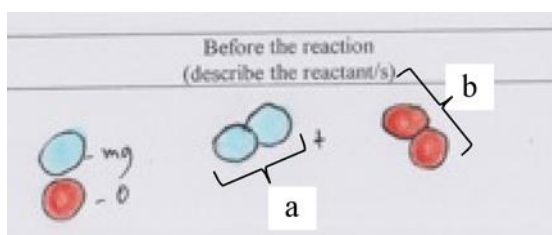
Student 3: Is it correct?

Student 1: They should be together.

Student 4: Because?

Student 1: But there should be two (molecules). Draw two separate O_2 .

(Peer-feedback on Student 3)

Figure 53 *Student 3's Drawing*

Further on the exchanges between peers on the drawing of Student 3 (Figure 53), peers (Student 5 and 4) posed questions that sought clarification on why the oxygen was drawn as two particles together. Hence it did not appear as gas but rather as solid. Yet, another peer (Student 1) affirmed that two oxygen atoms should be together to show it as a diatomic molecule. Then Student 1 pointed out that by drawing only one diatomic molecule of oxygen, Student 3 cannot show the empty spaces between the molecules of oxygen gas. Student 1 noted that two separate oxygen molecules should be drawn to precisely show oxygen as a gas.

It appeared that both teacher-feedback and peer-feedback considered the accurate drawing of the distance between particles of both solid and gaseous chemical species in the chemical reaction. Also both teacher-feedback and peer-feedback often used the ‘Identifying an idea’ *move*. Peer-feedback also often used the ‘Finding out more about an idea’ *move* (see Figure 33).

Quantitatively the teacher generated four times more feedback episodes than the peers (22 vs. 5) (see Table 50). Hence teacher-feedback students had a more frequent engagement with the feedback ideas on the accurate distance between particles of the solid and gaseous chemical species. Table 55 presents a summary of the results on the quantitative and qualitative differences between teacher-feedback and peer-feedback *focus* on ‘distance between particles’ for the combination reaction.

Table 55 *Quantitative and Qualitative Differences Between Teacher-Feedback and Peer-Feedback Focus on ‘Distance Between Particles’ for the Combination Reaction*

Teacher-feedback	Peer-feedback
<i>Distance between particles</i>	
(a) Generated more feedback episodes (22 episodes) than the students’ peers	(a) Generated five feedback episodes
(b) Frequently used ‘Identifying an idea’ as <i>feedback move</i>	(b) Frequently used ‘Identifying an idea’ and ‘Finding out more about an idea’ as <i>feedback moves</i>
(c) Pointed out the correct spaces between particles for both solid (compact) and gaseous (far apart) chemical species	(c) Similar to the teacher, peers pointed out the correct spaces between particles for both the solid and gaseous chemical species
(d) Identified drawing more particles of the solid and gaseous chemical species to show the phases more precisely	(d) A peer identified drawing additional particles of the gaseous chemical species to precisely show its phase

9.2.5 Overall Quality of the Drawing

For the overall quality of the drawing, the teacher asked students for additional ideas about their drawings. This is illustrated in the following teacher’s feedback on the drawing of Group 4 (Figure 54):

What else can you add to the sketch?

(Teacher-feedback on Group 4)

Figure 54 *Group 4's Drawing*

A student asked a question about the accuracy of his/her drawing. However the corresponding response from a peer expressed uncertainty about it. This is illustrated in the following exchange between peers while looking at the drawing of Student 1 (Figure 55):

Student 1: Do you think that we are doing this correctly?

Student 4: I am not sure.

(Peer-feedback on Student 1)

Figure 55 *Student 1's Drawing*

In Student 1's drawing the following were not accurately drawn: (1) oxygen (O_2) is drawn as an atom, not as a diatomic molecule; (2) mass (or particle) conservation was not observed for oxygen; and (3) magnesium oxide is not drawn as alternating magnesium and

oxygen particles but as alternating rows and columns of magnesium and oxygen particles.

Yet when Student 1 asked if what he/she had done was accurate a peer (Student 4) responded that he/she was not sure and did not identify any of the above-mentioned errors.

It appeared that while both the teacher and a peer utilised posing of questions that sought further information to deliver feedback, they used it for different purposes. The question posed by the teacher appeared to direct students' attention and thoughts about missing details in the drawing; so that students might have been able to address these details in their revised work. The question posed by a student coupled with the response of a peer suggested that they were uncertain about their ideas in the drawing.

Quantitatively the teacher generated three times fewer feedback episodes than peers (3 vs 9) (see Table 50). These fewer feedback episodes might be because in general the teacher was more likely to address specific visual and spatial ideas in the drawing rather than the overall drawing. The teacher had consistently generated a greater number of feedback episodes than the peers across all the four *feedback foci* (i.e., the identity of the chemical species, conservation of particles, arrangement of particles or distance between particles). Peers, compared to the teacher, generated more feedback episodes about the overall quality of the drawing but fewer feedback episodes across the same four *feedback foci*; although peers appeared uncertain about their ideas on the overall drawing. Table 56 presents a summary of the results on the quantitative and qualitative differences between teacher-feedback and peer-feedback *focus* on the 'overall quality of the drawing' for the combination reaction.

Table 56 *Quantitative and Qualitative Differences Between Teacher-Feedback and Peer-Feedback Focus on ‘Overall Quality of the Drawing’ for the Combination Reaction*

Teacher-feedback	Peer-feedback
<i>Overall quality of the drawing</i>	
(a) Generated less feedback episodes (3 episodes) than the students’ peers	(a) Generated nine feedback episodes
(b) Utilised ‘Finding out more about an idea’ as <i>feedback move</i>	(b) Frequently utilised ‘Finding out more about an idea’ and ‘Identifying an idea’ as <i>feedback moves</i>
(c) Posed a question to improve drawing in the revised work	(c) Question posed together with the corresponding response demonstrated uncertainty of drawing ideas

The results on the qualitative and quantitative analysis of teacher-feedback and peer-feedback *focus* on the ‘visual-spatial elements of the drawing’ category for the combination reaction, a chemical reaction involving identity transformation, demonstrated the following characteristics of teacher-feedback and peer-feedback:

1. Both teacher-feedback and peer-feedback pointed out how to accurately draw the distance between particles of both the solid (compact) and gaseous (far apart) chemical species. Also, both teacher-feedback and peer-feedback identified the need to draw more particles to precisely show the phases of the chemical species while using the correct spaces between the particles.
2. Teacher-feedback generated a greater number of feedback episodes than peer-feedback in all four *feedback foci*: Identity of the chemical species, conservation of particles, arrangement of particles, and distance between particles. This suggests that teacher-feedback was more akin than peer-feedback at specifically addressing each visual and spatial element of the drawing.

3. Teacher-feedback explained not only the identities but also the properties (i.e., charges) of the particles of both reactants (magnesium atoms and oxygen molecules) and product (magnesium oxide made up of Mg^{2+} and O^{2-} ions). Peer-feedback identified the identities of the particles of reactants but not the product.
4. Teacher-feedback recognised identity transformation from atoms to ions while peer-feedback did not.
5. Teacher-feedback pointed out the proper application of the Law of Conservation of Mass (or Particles) in the drawings. Peer-feedback was uncertain about how to show the Law of Conservation of Mass (or Particles) in the drawings.
6. Teacher-feedback explained the arrangement of the particles of a reactant (magnesium, a metallic crystal) and product (magnesium oxide, an ionic crystal). Peer-feedback identified the arrangement of the particles of a reactant (magnesium).
7. Both teacher-feedback and peer-feedback were often delivered by 'Identifying an idea' as a *feedback move*. Additionally, teacher-feedback frequently provided explanations that may have reinforced a better understanding of the feedback ideas. Peer-feedback however frequently posed questions. Such questions often did not lead to accurate drawing ideas and suggested that students were uncertain about their feedback ideas.

Nevertheless, there were few occasions where teacher-feedback and peer-feedback used chemical vocabulary that suggested ambiguity.

1. Teacher-feedback was sometimes implicit about the descriptive level (submicroscopic macroscopic or symbolic) of the identity of the particles (atoms and ions) of the chemical species.
2. Both teacher-feedback and peer-feedback were implicit about the arrangement of magnesium atoms as stacked above each other in a regular pattern. Teacher-feedback

was also implicit about the arrangement of the particles of the product, i.e., as regularly alternating magnesium (Mg^{2+}) and oxygen (O^{2-}) ions. Peer-feedback did not comment on the arrangement of the particles of the product.

The following section presents the quantitative and qualitative analysis of the *feedback focus* on ‘verbal linkages with the drawing’ category.

9.3 Feedback on Verbal Linkages with the Drawing

Table 57 presents the frequency of feedback episodes for each *feedback focus* in the teacher-feedback and peer-feedback groups for the combination reaction in the ‘verbal linkages with the drawing’ category.

Table 57 *Frequency of Episodes for Each Feedback Focus in the Teacher-Feedback and Peer-Feedback Groups in the ‘Verbal Linkages with the Drawing’ Category for the Combination Reaction*

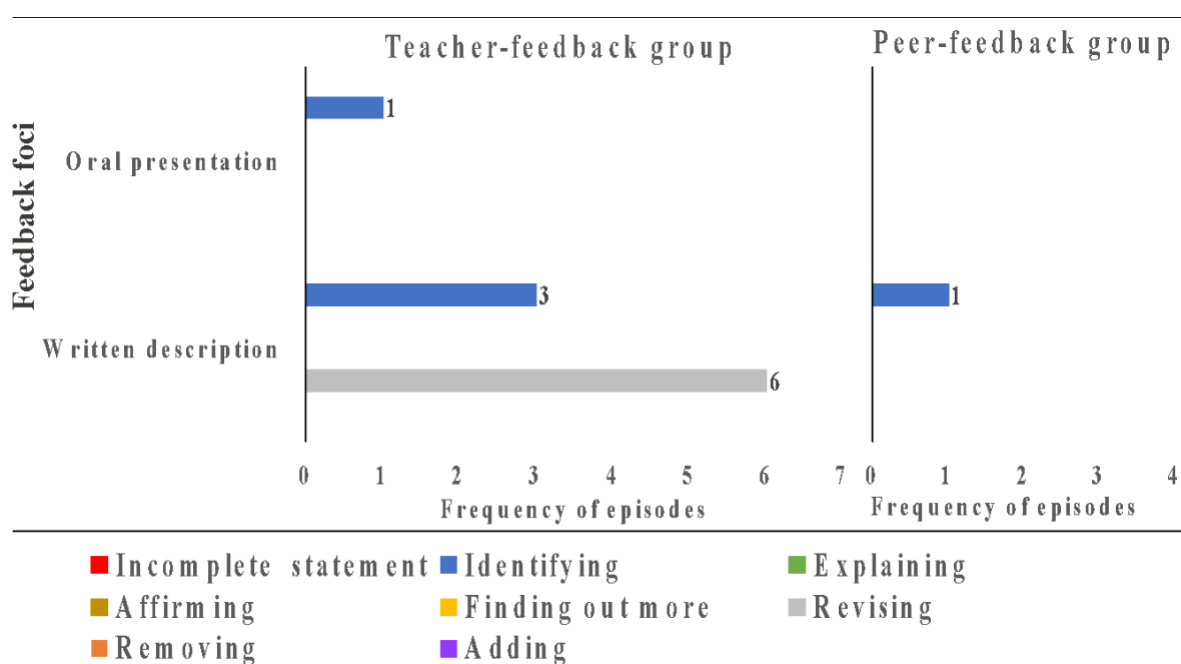
<i>Feedback focus</i>	Teacher-feedback group	Peer-feedback group
Written description of the drawing	9	1
Oral presentation	1	0
Total	10	1

Table 57 shows that the teacher generated a total of 10 feedback episodes while peers had only one feedback episode. It appeared that among the four categories of *feedback foci*, the ‘verbal linkages with the drawing’ category had the least number of feedback episodes from both groups. Both the teacher and peers did not give much feedback about how words (written or oral) were utilised to communicate the submicroscopic ideas in the drawing. Additionally, the greater number of feedback episodes of the teacher over the students’ peers suggest that compared to peer-feedback teacher-feedback recognised most, if not all aspects,

associated with the drawing task. This includes the use of words (written or oral) to support the communication of submicroscopic ideas represented in the drawing.

Furthermore, in the teacher-feedback group the most frequent *feedback focus* was the ‘written description of the drawing’. For the ‘oral presentation’, the teacher generated just one feedback episode. For *feedback moves*, Figure 56 shows that for ‘written description of the drawing’, the teacher frequently delivered feedback via ‘Revising an idea’. The only *feedback move* used for ‘oral presentation’ was ‘Identifying an idea’. The *focus* of teacher-feedback was on the description that students wrote to describe their drawings. Teacher-feedback on the written description usually asked students to replace their ideas. In the oral presentation by students during the whole class presentation, the teacher identified a single feedback. Examples of such *feedback focus* ideas and *feedback moves* are presented in Sections 9.3.1 and 9.3.2.

Figure 56 Comparison Between the Teacher-Feedback and Peer-Feedback Moves Used in the ‘Verbal Linkages with the Drawing’ Category for the Combination Reaction



In the peer-feedback group, as shown in Table 57, there was no feedback episode focused on the ‘oral presentation’ and only one feedback episode focused on the ‘written description of the drawing’. For *feedback moves*, as shown in Figure 56, the only *feedback move* used was ‘Identifying an idea’ for the ‘written description of the drawing’. A peer identified a single feedback on the written but not on the oral explanation of the drawing. Section 9.3.1 presents this single feedback episode of the peer for the written description of the drawing.

It appeared that regarding the verbal elements associated with the drawing, both teacher and peers were more focused on the written rather than the oral description of the drawing. Yet the teacher asked students to replace their ideas to improve their written description while a peer identified an idea on the drawing. Also, unlike peers, the teacher accounted for both the written and oral description of the drawings. Table 58 presents a summary of the results on the general quantitative and qualitative differences between teacher-feedback and peer-feedback in the ‘verbal linkages with the drawing’ category for the combination reaction.

Table 58 *General Quantitative and Qualitative Differences Between Teacher-Feedback and Peer-Feedback in the ‘Verbal Linkages with the Drawing’ Category for the Combination Reaction*

Teacher-feedback	Peer-feedback
<i>Verbal linkages with the drawing</i>	
(a) Generated more total feedback episodes (10 episodes) than the students’ peers	(a) Generated one feedback episode
(b) <i>Feedback foci</i> concentrated on the written description of the drawing	(b) <i>Feedback foci</i> concentrated on the written description of the drawing
(c) Frequently used ‘Revising an idea’ as <i>feedback move</i>	(c) Used ‘Identifying an idea’ as the only <i>feedback move</i>

(d) Had one feedback episode on the oral presentation using ‘Identifying an idea’ as *feedback move*

(d) Had no feedback on the oral presentation

The following sections discuss in greater details how the quality of feedback differs for the teacher-feedback and peer-feedback groups in each of the two *feedback foci* in the ‘verbal linkages with the drawing’ category: (a) written description of the drawing and (b) oral presentation.

9.3.1 Written Description of the Drawing

For the *feedback focus* on ‘written description of the drawing’, teacher-feedback students usually wrote about their macroscopic observations from the practical work. Consequently, the teacher frequently asked students to change their written description of the drawing from describing the macroscopic observations to describing the general submicroscopic ideas depicted as visual-spatial elements of the drawing. The following teacher’s feedback on the drawing of Group 1 (Figure 57) illustrates the teacher asking students to change their written description.

Okay, so the words should be about the general *reaction* and not about your *observations*.

So, you revise that part (pointing at ‘a’); that is your observation.

(Teacher-feedback on Group 1)

Figure 57 Group 1's Drawing and Written Description

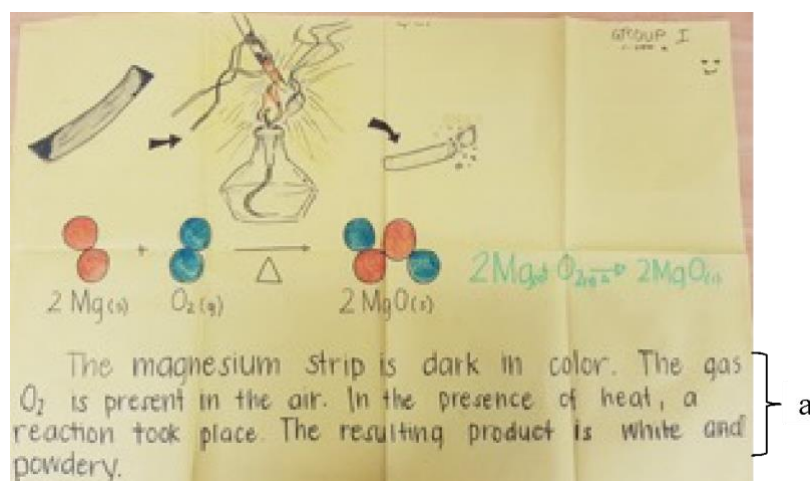
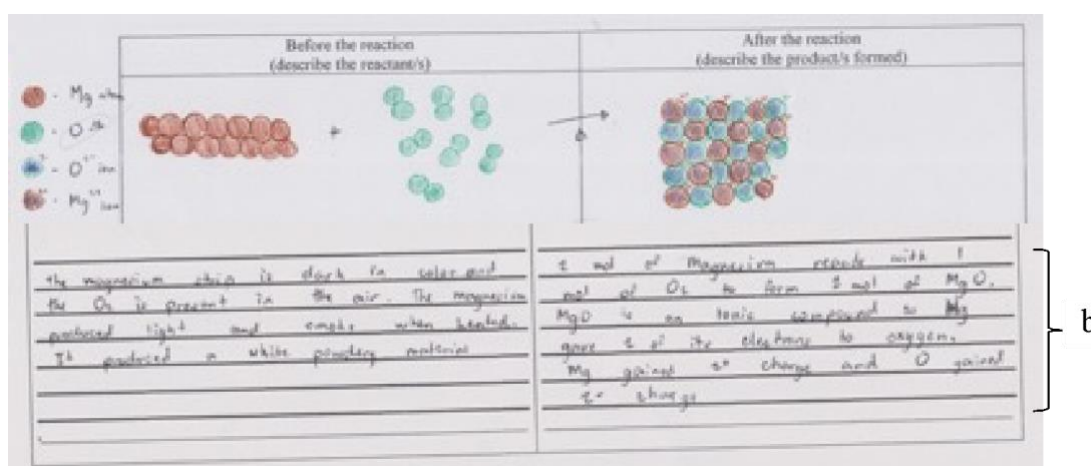


Figure 58 Group 1's Revised Drawing and Written Description



In the feedback the teacher referred to the submicroscopic ideas about the chemical reaction as 'reaction'. This was surmised from the changes made in the revised written description of Group 1 (Figure 58). After receiving teacher-feedback a student wrote not only about the macroscopic observations but also the submicroscopic ideas, i.e., identity transformation (see 'b'). Furthermore, in the revised written description of Group 1 (Figure 58), it was explained why and how magnesium (Mg^{2+}) and oxygen (O^{2-}) ions were formed as products. This detail on the transfer of valence electrons from magnesium to oxygen was not captured in the drawing. It appeared that the written description served as an additional

supporting modality to discern how students attempted to process information presented to them during drawing (Davidowitz et al., 2010). The written description contributed to a better view of students' overall understanding beyond what was represented in the drawing (Ryan & Stieff, 2019).

Peer-feedback students also often wrote their macroscopic observations in the written description. In the only peer-feedback for the 'written description of the drawing' a peer pointed out that 'correct words' should be used for the written description. This is shown in the following peer's feedback on the drawing of Student 5 (Figure 59):

It is all up to you, just make sure that you use the *correct words*.

(Peer-feedback on Student 5)

Figure 59 Student 5's Drawings and Written Description



Since no subsequent explanation was given by the peer it was uncertain what the peer meant about 'correct words'. The peer might have been affirming that it was acceptable to write about the macroscopic observations but correct terms should have been used.

Alternatively, it may have also meant that the correct name of the chemical species or correct identity of the particles of each chemical species should have been used. If the peer referred to the use of correct terms to describe macroscopic observations, then the peer-feedback did

not account for the submicroscopic ideas in the written description. If the peer referred to ‘correct words’ as the correct name of the chemical species, then the written description of Student 5 was able to correctly name the reactants (magnesium and oxygen) but not the product since magnesium oxide was not mentioned. If the peer referred to ‘correct words’ as the correct identity of the particles of each chemical species (molecules), then the written description of Student 5 did not address it. In none of the cases did peer-feedback precisely point out what was lacking in the written description in terms of submicroscopic events, e.g., identity transformation.

It appeared that teacher-feedback was more explicit about connecting the written description to the visual-spatial representation (drawing). The teacher, by asking students to change the written description, prompted them to think directly about their submicroscopic ideas in the drawing (and not about the macroscopic observations) and how to explain them in the written description. Teacher-feedback recognised the use of the written description in supporting better communication and understanding of the overall submicroscopic ideas in the drawing. However, teacher-feedback utilised chemical vocabulary like ‘reaction’ and ‘observations’ to refer to submicroscopic ideas and macroscopic observations, respectively. Such implicit chemical vocabulary could have potentially posed ambiguity for other students. The same was true for peer-feedback. On one occasion peer-feedback pinpointed that correct words should be used in the written description. Yet the student did not specifically identify what ‘correct words’ means (i.e., name of the chemical species or identity of the particles of each chemical species) and what written description his/her peer should come up with (i.e., about the overall submicroscopic ideas or the macroscopic observations). Peer-feedback did not seem to recognise that the written description should support the communication and understanding of the submicroscopic ideas in the drawing.

Quantitatively, as seen in Table 57, the teacher generated nine feedback episodes while peers generated only one feedback episode for the ‘written description of the drawing’. Because students were prompted to write their submicroscopic ideas as the written description, the greater number of feedback episodes may have prompted teacher-feedback students to specifically think more often about their understanding of the submicroscopic ideas in their drawings. Table 59 presents a summary of the results on the quantitative and qualitative differences between teacher-feedback and peer-feedback *focus* on ‘written description of the drawing’ for the combination reaction.

Table 59 *Quantitative and Qualitative Differences Between Teacher-Feedback and Peer-Feedback Focus on ‘Written Description of the Drawing’ for the Combination Reaction*

Teacher-feedback	Peer-feedback
<i>Written description of the drawing</i>	
(a) Generated more feedback episodes (nine episodes) than the students’ peers	(a) Generated one feedback episode
(b) Frequently utilised ‘Revising an idea’ as <i>feedback move</i>	(b) Utilised ‘Identifying an idea’ as the <i>feedback move</i>
(c) Linked the written description to the visual-spatial ideas of the drawing. Yet, used implicit chemical vocabulary, i.e., ‘reaction’ and ‘observations’	(c) Mentioned that ‘correct words’ should be used in the written description. However, it was uncertain what ‘correct words’ means.

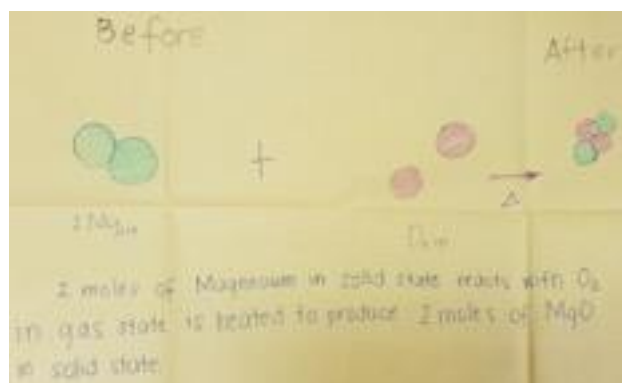
9.3.2 Oral Presentation

For the ‘oral presentation’ the teacher pointed out that the oral presentation of Group 4 about their drawing (Figure 60) was too simple. This is illustrated in the following teacher’s feedback:

Very simple, very simple is your (oral) presentation.

(Teacher-feedback on Group 4)

Figure 60 Group 4's Drawing and Written Description



This teacher-feedback on Group 4's drawing (Figure 60) was given because the group representative presenting before the whole class simply read the written description of the drawing: *"Two moles of Mg in the solid state reacts with O_2 in gas state and is heated to produce two moles of MgO in the solid state"* (Student 7, Group 4). The teacher was probably expecting that the representative would say more regarding the submicroscopic ideas (visual-spatial elements) in the drawing, and how those submicroscopic ideas relate to the macroscopic observations and the balanced chemical equation. Peers however did not give any feedback on the oral presentation during their in-group exchanges.

It appeared that compared to the written description, both the teacher and peers were less concerned about how ideas in the drawings were presented orally. Perhaps, the teacher had a feedback episode on this *feedback focus* because he was prompted by the short, quick, and simple presentation of Group 4, which was not typical among the eight teams who presented. The oral presentation of Group 4 did not go unnoticed by the teacher. Unlike the peers, the teacher accounted for most, if not all, aspects pertinent to the drawing task for the combination reaction. These aspects include both the written and oral explanation that

support communication and understanding of the ideas (especially submicroscopic ideas) in the drawing. Table 60 presents a summary of the results on the quantitative and qualitative differences between teacher-feedback and peer-feedback *focus* on ‘oral presentation’ for the combination reaction.

Table 60 *Quantitative and Qualitative Differences Between Teacher-Feedback and Peer-Feedback Focus on ‘Oral Presentation’ for the Combination Reaction*

Teacher-feedback	Peer-feedback
<i>Oral presentation</i>	
(a) Delivered one feedback episode via ‘Identifying an idea’ as <i>feedback move</i>	(a) Did not give any feedback

The findings on the qualitative and quantitative analysis of teacher-feedback and peer-feedback on the ‘verbal linkages with the drawing’ category for the combination reaction demonstrated the following characteristics of teacher-feedback and peer-feedback:

1. Teacher-feedback commented on both the written and oral modes of communicating and understanding the ideas (especially submicroscopic ideas) in the drawings. Teacher-feedback on the written description was often delivered via ‘Revising an idea’. ‘Identifying an idea’ was used for the oral presentation. Peer-feedback only commented on the written mode via ‘Identifying an idea’.
2. Teacher-feedback made explicit the purpose of a written description of the drawing, which was to support communication and understanding of the submicroscopic ideas depicted in the drawing. Peer-feedback used an ambiguous phrase in the written description: ‘correct words’. In effect, peer-feedback did not directly point out that the written description should be about the submicroscopic ideas in the drawing and not just on macroscopic observations from the practical work.

3. In the written description of the drawing, teacher-feedback generated more feedback episodes than peer-feedback. Such a greater number of feedback episodes may have prompted teacher-feedback students more often than peer-feedback students to think about their submicroscopic ideas in the drawings as they are communicated via their written description.

The next section presents the quantitative and qualitative analysis of the feedback on the ‘triplet relationship’ category.

9.4 Feedback on the Triplet Relationship

Table 61 presents the frequency of feedback episodes for each *feedback focus* in the teacher-feedback and peer-feedback groups for the combination reaction in the ‘triplet relationship’ category.

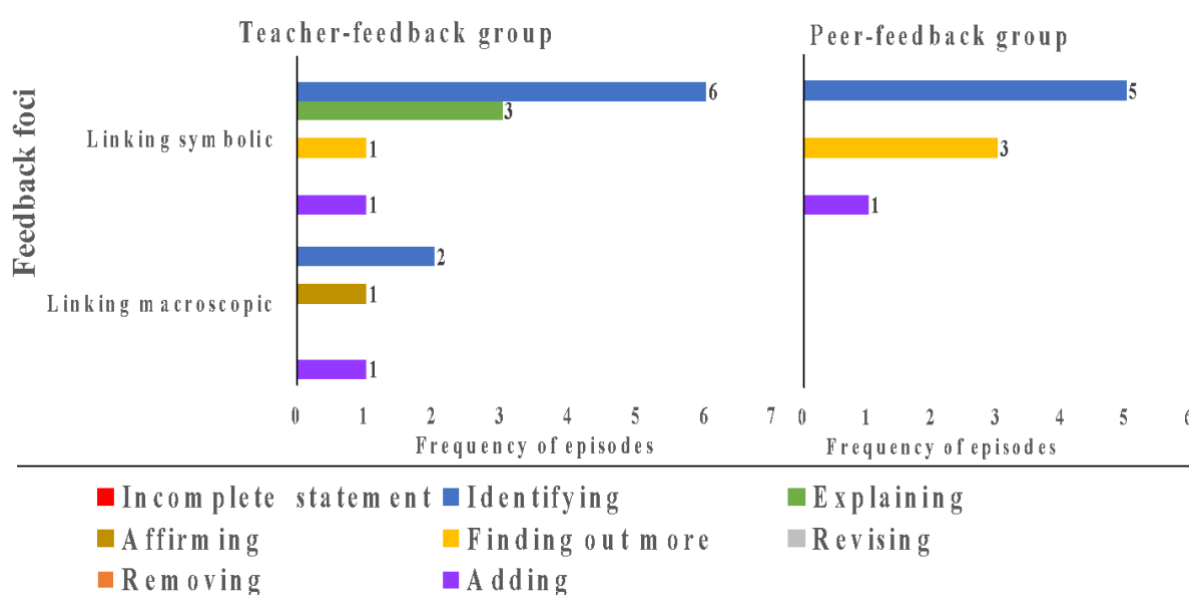
Table 61 *Frequency of Feedback Episodes for Each Feedback Focus in the Teacher-Feedback and Peer-Feedback Groups in the ‘Triplet Relationship’ Category for the Combination Reaction*

<i>Feedback focus</i>	Teacher-feedback group	Peer-feedback group
Linking symbolic representation (i.e., chemical equation)	11	9
Linking macroscopic observation	4	0
Total	15	9

Table 61 shows that the teacher generated more total feedback episodes than the peers (15 vs. 9). Moreover, the teacher’s most frequent *feedback focus* was ‘linking symbolic representation (i.e., chemical equation)’. For *feedback moves* the teacher frequently used the ‘Identifying an idea’ *move* for both ‘linking symbolic representation’ and ‘linking macroscopic observation’ as shown in Figure 61. Yet for ‘linking symbolic representation’ the teacher also used the ‘Explaining an idea’ *move*. In the ‘triplet relationship’ category the

focus of teacher-feedback was on whether the chemical equation concurred with the submicroscopic ideas in the drawing with less focus on linking macroscopic observations from the practical work to the submicroscopic ideas in the drawing. Additionally, the teacher provided explanations to substantiate feedback ideas about linking the chemical equation to the submicroscopic ideas. For feedback on linking the macroscopic observations from the practical work to the submicroscopic ideas, the teacher did not provide an explanation. Examples of such *feedback focus* ideas and *feedback moves* are presented in Sections 9.4.1 and 9.4.2.

Figure 61 Comparison Between the Teacher-Feedback and Peer-Feedback Moves Used in the ‘Triplet Relationship’ Category for the Combination Reaction



In the peer-feedback group students only gave feedback on the ‘linking symbolic representation (i.e., chemical equation)’ (see Table 61). There was no feedback episode on ‘linking macroscopic observation’. For *feedback moves* peers frequently delivered feedback on ‘linking symbolic representation (i.e., chemical equation)’ via ‘Identifying an idea’ (see Figure 61). The *focus* of peer-feedback was the same as teacher-feedback which was on

whether the chemical equation concurred with the submicroscopic ideas in the drawing. Yet students did not provide explanations to substantiate their feedback ideas. An example of such *feedback focus* ideas and *feedback move* is presented in Section 9.4.1. Also, peers did not attempt to link their macroscopic observations from the practical work and submicroscopic ideas in the drawing.

The chemistry triplet is made up of three ‘domains’ or ‘levels’ of chemical knowledge, namely: the macroscopic, submicroscopic, and symbolic. In my research study, the practical work on the combustion of magnesium including the observations from it relates to the macroscopic domain; the visual-spatial elements of the drawing relate to the submicroscopic domain; the chemical equation of the chemical reaction relates to the symbolic domain. From the foregoing discussion of the comparison between teacher-feedback and peer-feedback in the ‘triplet relationship’ category, it appeared that both teacher-feedback and peer-feedback was focused on the symbolic domain. However, the teacher frequently provided explanations while peers did not. Those explanations may have reinforced the feedback ideas better for the teacher-feedback students. Also, it was only teacher-feedback that examined the linkages among the three domains of the chemistry triplet. Peer-feedback did not account for the linkage between the macroscopic and submicroscopic domains. Table 62 presents a summary of the results on the general quantitative and qualitative differences between teacher-feedback and peer-feedback in the ‘triplet relationship’ category for the combination reaction.

Table 62 General Quantitative and Qualitative Differences Between Teacher-Feedback and Peer-Feedback in the ‘Triplet Relationship’ Category for the Combination Reaction

Teacher-feedback	Peer-feedback
<i>Triplet relationship</i>	
(a) Generated more total feedback episodes (15 episodes) than the students’ peers	(a) Generated nine total feedback episodes
(b) <i>Feedback foci</i> concentrated on linking the chemical equation with the submicroscopic ideas in the drawing	(b) <i>Feedback foci</i> was like teacher-feedback. It concentrated on linking the chemical equation with the submicroscopic ideas in the drawing
(c) There was <i>feedback focus</i> on linking the macroscopic observations from the practical work and the submicroscopic ideas in the drawing	(c) No feedback on linking the macroscopic observations from the practical work and the submicroscopic ideas in the drawing
(d) Frequently used ‘Identifying an idea’ as <i>feedback move</i> for the two <i>feedback foci</i> . Yet, also utilised ‘Explaining an idea’ for <i>feedback focus</i> on ‘linking symbolic representation (i.e., chemical equation)’	(d) Frequently used ‘Identifying an idea’ and ‘Finding out more about an idea’ as <i>feedback moves</i> for <i>feedback focus</i> on ‘linking symbolic representation (i.e., chemical equation)’

The next sections discuss further how the quality of feedback differed for the teacher-feedback and peer-feedback groups in the two *feedback foci* in the ‘triplet relationship’ category: (a) linking symbolic representation (i.e., chemical equation), and (b) linking macroscopic observation.

9.4.1 Linking Symbolic Representation (i.e., Chemical Equation)

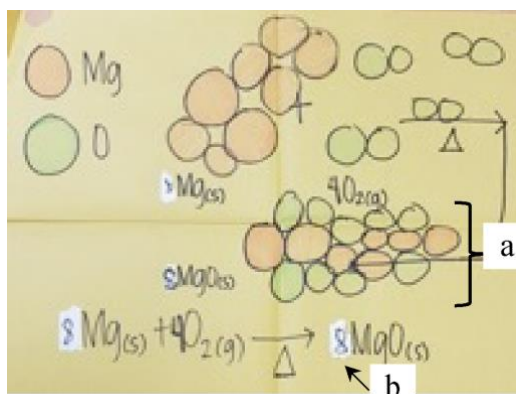
For the *feedback focus* on ‘linking symbolic representation’ the teacher identified that the submicroscopic ideas in the drawing should concur with the chemical equation. The teacher checked the number of particles of each chemical species in the drawing if it matched the ratio of the coefficients in the chemical equation. In the following teacher’s feedback on the drawing of Group 5 (Figure 62), the teacher pinpointed that the number of magnesium

(seven) and oxygen (nine) particles in the product side (see 'a') did not match the coefficient (eight) for MgO in the balanced chemical equation (see 'b').

That number of atoms (pointing at 'a') does not match the coefficient in the equation (pointing at 'b').

(Teacher-feedback on Group 5)

Figure 62 *Group 5's Drawing*

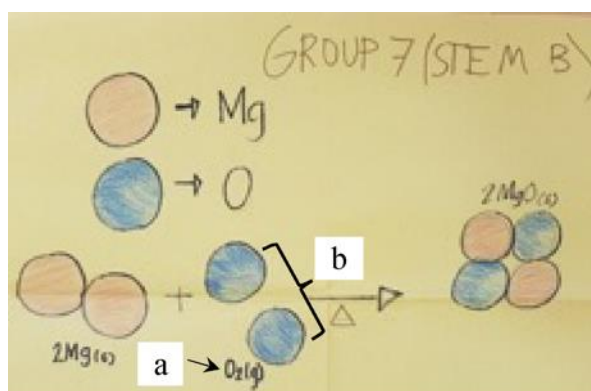


The teacher also explained the correct chemical formula in relation to the correct identity of the particles of each chemical species in the drawing. This is illustrated in the following feedback on the drawing of Group 7 (Figure 63) where the teacher pointed out that drawing two atoms of oxygen was not consistent with the chemical formula O₂. The teacher then explained that the oxygen atoms should instead be drawn as a diatomic molecule:

So, the equation for that (pointing at 'b') is 2O , not O_2 (pointing at 'a'). If you have that one (pointing at 'b'), the equation for that is 2O , not O_2 (pointing at 'a') because you had two oxygen atoms. But that should not be oxygen atoms. That should be an oxygen molecule, O_2 (pointing at 'b'), meaning that there are two oxygen atoms joined together by a bond.

(Teacher-feedback on Group 7)

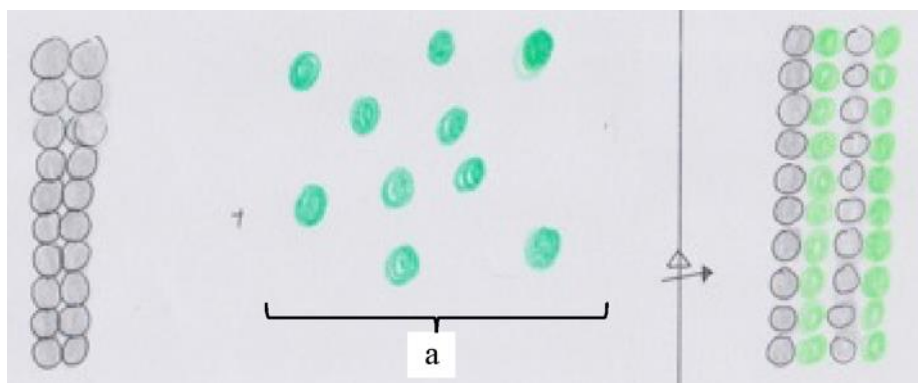
Figure 63 Group 7's Drawing



Meanwhile a peer pointed out that the lowest possible set of coefficients should be used to balance the chemical equation. This is illustrated in the following peer's feedback on the drawing of Student 1 (Figure 64):

But in terms of balancing the equation, we should use the lowest coefficients. What is that again? Lowest term (lowest possible set of coefficients).

(Peer-feedback on Student 1)

Figure 64 *Student 1's Drawing*

However, in Figure 64, the drawing of Student 1 did not match the balanced chemical equation: $2\text{Mg}_{(s)} + \text{O}_{2(g)} \rightarrow 2\text{MgO}_{(s)}$. The number of particles in the drawing did not match the correct ratio of particles indicated by the coefficients in the balanced chemical equation. Instead of two magnesium atoms for every *one molecule* of diatomic oxygen and two magnesium oxide ions (one magnesium ion and one oxide ion), the ratio of particles shown in the drawing is two magnesium atoms for every *one atom* of oxygen and two magnesium oxide ions. The oxygen in the drawing (see 'a') was drawn as an oxygen atom (O) while in the chemical equation it is a molecule (O_2). This deficient information was not addressed in the peer-feedback. Quantitatively the number of feedback episodes of the teacher and the peers were close to each other (11 vs. 9) (see Table 61). Both groups received roughly the same amount of feedback. Quality rather than quantity of feedback episodes was more likely to have contributed to a better understanding of the feedback ideas on linking the chemical equation (symbolic domain) with the submicroscopic ideas in the drawing.

Examination of the quality of *feedback focus* on 'linking symbolic representation' suggests that teacher-feedback made an accurate linkage between the submicroscopic ideas in the drawing and the chemical equation by pointing out that: (a) the number of particles of the chemical species in the drawing should match the corresponding ratio of the coefficients in

the balanced chemical equation; (b) the identity of the particles of the chemical species in the drawing should match the corresponding chemical formula in the chemical equation. Peer-feedback however did not make such accurate linkage between the submicroscopic ideas in the drawing and the chemical equation. Peer-feedback was focused on the chemical equation per se, i.e., recognising the lowest possible set of coefficients.

Moreover, such quality of teacher-feedback on ‘linking symbolic representation’ was supported with explanations, unlike peer-feedback. Those explanations may have reinforced a better understanding of the feedback ideas. Table 63 presents a summary of the results on the quantitative and qualitative differences between teacher-feedback and peer-feedback *focus* on ‘linking symbolic representation (i.e., chemical equation)’ for the combination reaction.

Table 63 *Quantitative and Qualitative Differences Between Teacher-Feedback and Peer-Feedback Focus on ‘Linking Symbolic Representation (i.e., Chemical Equation)’ for the Combination Reaction*

Teacher-feedback	Peer-feedback
<i>Linking symbolic representation (i.e., chemical equation)</i>	
(a) Generated 11 feedback episodes	(a) Generated nine feedback episodes
(b) Feedback focused on accurately linking the submicroscopic ideas in the drawing (i.e., identity and conservation of the particles) with the chemical equation	(b) Feedback did not focus on linking the submicroscopic ideas in the drawing with the chemical equation. Rather, it was only focused on the chemical equation (getting the lowest possible ratio of coefficients)
(c) Often utilised ‘Identifying an idea’ and ‘Explaining an idea’ as <i>feedback moves</i>	(c) Often utilised ‘Identifying an idea’ and ‘Finding out more about an idea’ as <i>feedback moves</i>

9.4.2 Linking Macroscopic Observation

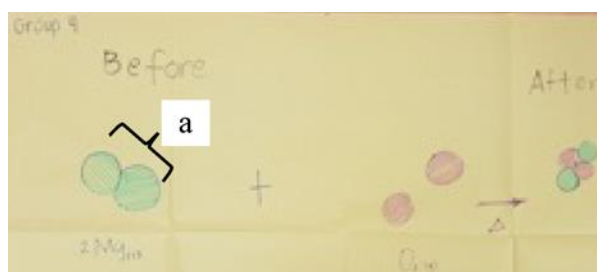
For *feedback focus* on ‘linking macroscopic observation’, the teacher made a linkage between the submicroscopic and the macroscopic domains. In the teacher’s feedback on the

drawings of Group 4 (Figure 65) and 5 (Figure 66), the teacher linked the macroscopic appearance of magnesium metal as a strip to the arrangement of its particles at the submicroscopic level.

Therefore, you need to include all the rest of the (magnesium) atoms in the strip in the illustration (pointing at 'a').

(Teacher-feedback on Group 4)

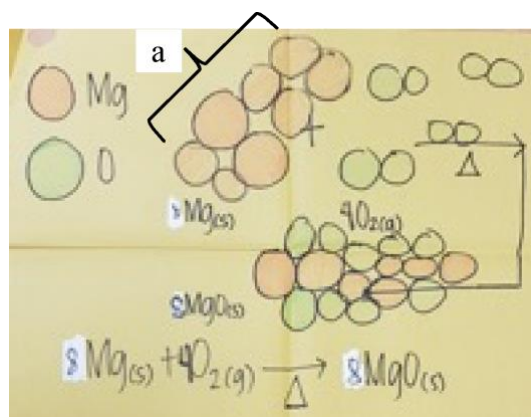
Figure 65 Group 4's Drawing



You can draw the entire solid structure of magnesium (pointing at 'a') because you're given a strip.

(Teacher-feedback on Group 5)

Figure 66 Group 5's Drawing



In Figure 66, Group 5 originally drew only two atoms of magnesium. But after receiving the teacher's feedback, the group added six more atoms to make it appear like a strip. These six additional atoms can be recognised from the drawing because they are smaller circles compared to the two original atoms. Peers did not give feedback on 'linking macroscopic observation'. Hence peers in their feedback did not demonstrate the connection between the submicroscopic ideas in the drawing and the macroscopic observations in the practical work.

It was likely that teacher-feedback students were made cognisant of the link between their submicroscopic ideas in the drawing and their macroscopic observations from the practical work because they received feedback about it. Peer-feedback students were less prompted to think about that link between their submicroscopic ideas in the drawing and their macroscopic observations from the practical work since they did not receive feedback about it. Table 64 presents a summary of the results on the quantitative and qualitative differences between teacher-feedback and peer-feedback *focus* on 'linking macroscopic observation' for the combination reaction.

Table 64 *Quantitative and Qualitative Differences Between Teacher-Feedback and Peer-Feedback Focus on 'Linking Macroscopic Observation' for the Combination Reaction*

Teacher-feedback	Peer-feedback
<i>Linking macroscopic observation</i>	
(a) Generated four feedback episodes	(a) No feedback was generated
(b) Linked the macroscopic appearance of magnesium strip to the arrangement of the particles at the submicroscopic level	(b) No feedback on linking the macroscopic and submicroscopic domains
(c) Frequently used 'Identifying an idea' as <i>feedback move</i>	(c) Exhibited no <i>feedback move</i>

The results on the qualitative and quantitative analysis of teacher-feedback and peer-feedback *focus* on the ‘triplet relationship’ category for the combination reaction, a chemical reaction involving identity transformation, demonstrated the following characteristics of teacher-feedback and peer-feedback:

1. Teacher-feedback made linkages between the chemistry triplet, i.e., submicroscopic domain (drawing), symbolic domain (chemical equation), and macroscopic domain (observations from the practical work). Peer-feedback was not able to make such linkages. There was no peer-feedback on linking the drawing to the observations from the practical work. Additionally, feedback on the symbolic domain was about the chemical equation per se and did not relate to the drawings.
2. The teacher often identified feedback ideas substantiated with explanations. Students’ peers often identified feedback ideas without an explanation. They also often posed questions asking for further ideas. The explanations provided by the teacher may have reinforced a better understanding of the feedback ideas.

The following section presents the quantitative and qualitative analysis of the feedback on the ‘prerequisite chemistry knowledge’ and ‘cannot identify content’ categories.

9.5 Feedback on Prerequisite Chemistry Knowledge and Cannot Identify Content

Table 65 presents the frequency of feedback episodes in the teacher-feedback and peer-feedback groups for the combination reaction in the feedback on ‘prerequisite chemistry knowledge’ and ‘cannot identify content’ categories.

Table 65 *Frequency of Feedback Episodes in the Teacher-Feedback and Peer-Feedback Groups in the ‘Prerequisite Chemistry Knowledge’ and ‘Cannot Identify Content’ Categories for the Combination Reaction*

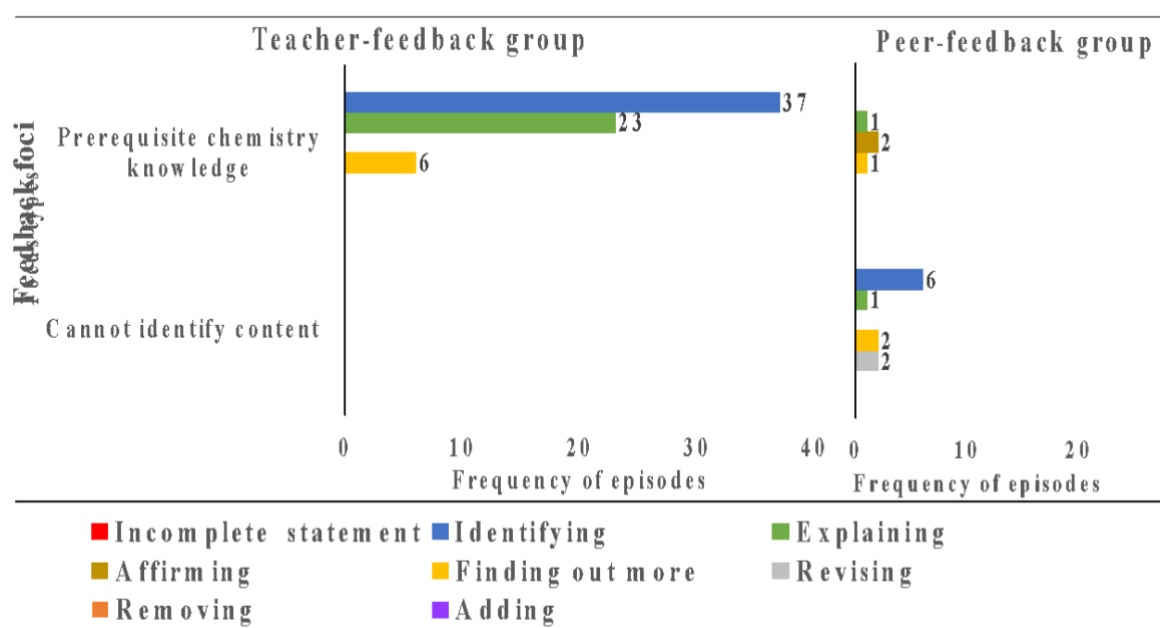
Feedback category	Teacher-feedback group	Peer-feedback group
Prerequisite chemistry knowledge	66	4
Cannot identify content	0	11

Table 65 shows that the teacher generated roughly 17 times more feedback episodes than the peers (66 vs. 4) in the ‘prerequisite chemistry knowledge’ category. Additionally, there was no feedback episode from the teacher and students’ peers had 11 feedback episodes in the ‘cannot identify content’ category. These results suggest that the teacher had given more feedback ideas on chemistry concepts that students learned from their previous chemistry lessons. These previously learned chemistry concepts were pertinent to the submicroscopic ideas (visual-spatial elements) in the drawing. Such a larger number of feedback ideas may have caused greater cognitive engagement of the teacher-feedback students with the chemistry concepts and the related submicroscopic ideas. Such increased cognitive engagement may have contributed to a better understanding of submicroscopic ideas in the drawing for the teacher-feedback students compared with the peer-feedback students. In the ‘cannot identify content’ category the teacher did not generate feedback episodes that were incomprehensible for the researcher even though he had a longer time than the students to give feedback (40 vs. 30 minutes). Teacher-feedback carried intelligible thoughts. Students’ peers generated 11 feedback episodes incomprehensible for the researcher. And given more time the students were more likely to generate additional incomprehensible feedback episodes.

For *feedback moves*, Figure 67 shows that for the ‘prerequisite chemistry knowledge’ category the teacher frequently used ‘Identifying an idea’ and ‘Explaining an idea’. The

teacher identified feedback ideas in the form of chemistry concepts that students learned from their previous chemistry lessons and were linked to the submicroscopic ideas in the drawing. Further, the teacher provided explanations to substantiate those feedback ideas. Examples of these feedback ideas and *feedback moves* are presented in Section 9.5.1. Additionally, since the teacher did not give any feedback on the ‘cannot identify content’ category, no *feedback move* was observed for that category.

Figure 67 Comparison Between the Teacher-Feedback and Peer-Feedback Moves Used in the ‘Prerequisite Chemistry Knowledge’ and ‘Cannot Identify Content’ Categories for the Combination Reaction



In the peer-feedback group, Figure 67 shows that in the ‘prerequisite chemistry knowledge’ category peers frequently used the ‘Affirming an idea’ *move*. This means that when giving feedback about chemistry concepts that they previously learned peers affirmed each other’s ideas. In the ‘cannot identify content’ category peers frequently used the ‘Identifying an idea’ *move*. This suggests that peers when giving unintelligible feedback the

feedback statement appeared to be identifying a particular idea. Examples of these feedback ideas and *feedback moves* are presented in Sections 9.5.1 and 9.5.2.

It appeared that the teacher generated a greater number of feedback ideas on previously learned chemistry concepts pertinent to the submicroscopic ideas in the drawing. More so the teacher often provided explanations to substantiate those feedback ideas while students' peers often affirmed each other's ideas. Also peer-feedback was often less comprehensible than teacher-feedback. The substantiating explanations and comprehensible feedback from the teacher may have cultivated an understanding of the previously learned chemistry concepts and the associated submicroscopic ideas. Table 66 presents a summary of the results on the general quantitative and qualitative differences between teacher-feedback and peer-feedback in the 'prerequisite chemistry knowledge' and 'cannot identify content' categories for the combination reaction.

Table 66 *General Quantitative and Qualitative Differences Between Teacher-Feedback and Peer-Feedback in the 'Prerequisite Chemistry Knowledge' and 'Cannot Identify Content' Categories for the Combination Reaction*

Teacher-feedback	Peer-feedback
<i>Prerequisite chemistry knowledge</i>	
(a) Generated more total feedback episodes (66 episodes) than the students' peers	(a) Generated four feedback episodes
(b) Frequently utilised 'Identifying an idea' and 'Explaining an idea' as <i>feedback moves</i>	(b) Frequently utilised 'Affirming an idea' as <i>feedback move</i>
<i>Cannot identify content</i>	
(a) Generated no feedback episode	(a) Generated 11 feedback episodes
(b) Exhibited no <i>feedback move</i>	(b) Frequently utilised 'Identifying an idea' as <i>feedback move</i> . However, the meaning of the feedback statement cannot be construed.

9.5.1 Prerequisite Chemistry Knowledge

As previously stated, the teacher gave a greater number of feedback episodes on previously learned chemistry concepts, which were related to the visual-spatial elements of the drawing. Examples include feedback on the concept of atoms, ions and molecules, and chemical behaviour of metals and nonmetals that were related to the ‘identity of chemical species’; and feedback on ionic bonding and structure of ionic compounds that were related to the ‘arrangement of particles’. These previously learned chemistry concepts served as espousing explanations to develop a deeper understanding of those visual-spatial elements. These previously learned chemistry concepts are listed below together with a sample feedback episode and corresponding drawing:

(a) Concept of atoms, ions, and molecules

To use the atom, it is for elements. For example, aluminum, aluminum atoms. A molecule consists of two or more atoms bonded together. And then when these atoms and molecules now bear charges either positive or negative, those are already ions. K^+ , Cl^- , Na^+ , F^- or O^{2-} . Those are ions. Remember last time in the acid (second practice lesson, which was about dissociation of ethanoic acid in water)? Ethanoic acid? You had there the H^+ and the CH_3COO^- . Those are ions.

(Teacher-feedback on Group 5)

Figure 68 *Group 5's Drawing*



This teacher-feedback on the drawing of Group 5 (Figure 68) about the difference between the concept of atoms, ions, and molecules was useful in supporting students to recognise and understand the identities of the particles of the chemical species involved in the chemical reaction: Magnesium as atoms, oxygen as molecules, and magnesium oxide as made up of ions.

(b) Chemical behaviour of metals and nonmetals

Magnesium is metal and oxygen is a nonmetal. Remember metals are electron donors and nonmetals are electron acceptors. Metals tend to donate their electrons to nonmetals because nonmetals require electrons to complete their outer shells. Metals have an excess of one, two or three electrons in their outer shell. But nonmetals require one, two or three to complete their shells. That's why in that case (pointing at Figure 68) the magnesium loses electrons to oxygen to form the bond.

(Teacher-feedback on Group 5)

(c) Octet rule

How many electrons can be given away by magnesium? And how many electrons can be taken by oxygen to build their outer shell to 8 electrons?

(Teacher-feedback on Group 4)

Figure 69 *Group 4's Drawing*



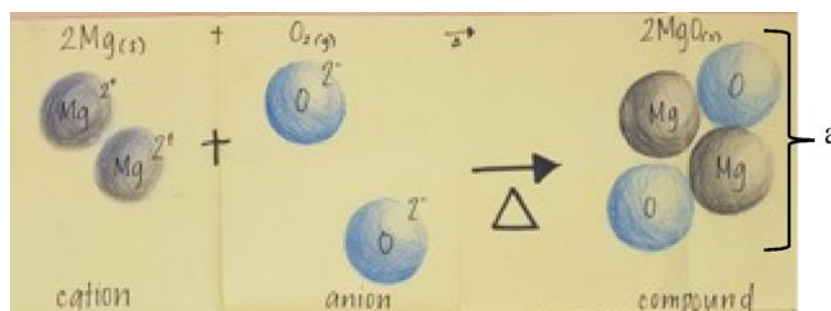
The teacher-feedback on the drawings of Groups 5 (Figure 68) and 4 (Figure 69) about the chemical behaviour of metals and nonmetals, and octet rule (respectively) were useful in supporting students to recognise identity transformation from reactants to product, i.e., from magnesium atoms (Mg) and oxygen molecules (O_2) to magnesium (Mg^{2+}) and oxygen (O^{2-}) ions.

(d) Ionic bonding and structure of ionic compounds

That electrostatic attraction between Mg^{2+} and O^{2-} provides the bond for the compound (pointing at 'a'). That is, Mg bonded to O now because of the virtue of electrostatic attraction.

(Teacher-feedback on Group 2)

Figure 70 Group 2's Drawing



The crystal structure of an ionic compound let's say, for example, sodium chloride, $NaCl$ – Each Na^+ is surrounded by several negatively charged Cl^- and each Cl^- ion is surrounded by several positively charged Na^+ ion. And that is the ionic bond.

(Teacher-feedback on Group 5)

The teacher-feedback on the drawings of Groups 2 (Figure 70) and 5 (Figure 68) about ionic bonding and structure of ionic compounds were useful to explain the arrangement of the particles of the product, magnesium oxide, which has an ionic crystalline structure.

(e) Mole as a measure of the amount of substance

That strip (magnesium metal strip) consists of several atoms. Because we know that a mole of an atom or a mole of anything contains 6.02×10^{23} particles.

(Teacher-feedback on Group 5)

The teacher-feedback on the drawing of Group 5 (Figure 68) about the mole as a measure of the amount of substance may have supported the linkage between the number and arrangement of magnesium atoms in the solid phase and its macroscopic appearance as a metal strip ('linking macroscopic observation').

Peer-feedback on the 'prerequisite chemistry knowledge' category was focused on a single previously learned chemistry concept – the mole, i.e., the difference between an atom and mole in terms of size. This is illustrated in the following exchanges between peers about the drawing of Student 6 (Figure 71). In the exchanges a peer (Student 4) affirmed the ideas about the mole given by other peers (Students 6 and 1).

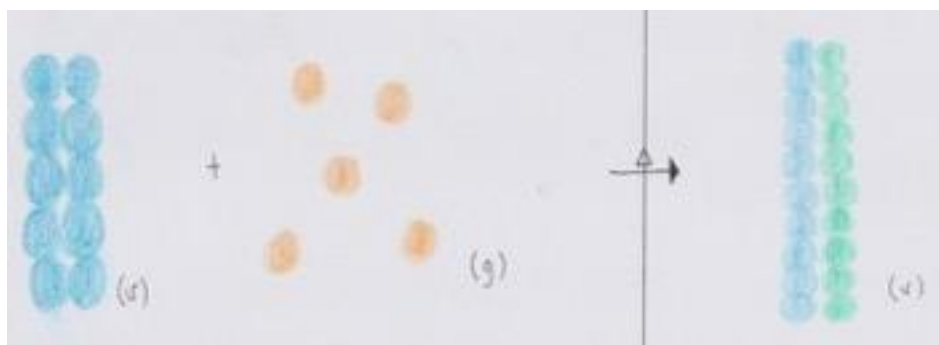
Student 6: Which one is smaller? Atom is smaller than a mole, right?

Student 4: Yeah!

Student 1: Mole is the number of, the amount of substance.

Student 4: Oh yes, right!

(Peer-feedback on Student 6)

Figure 71 *Student 6's Drawing*

Initially Student 6 thought that mole is a chemical species (like atoms, ions, and molecules) and not a measure of the number of particles of these chemical species. Subsequently Student 4 affirmed Student 6's idea by responding 'yeah'. Yet another peer, Student 1, corrected this by pinpointing that mole is the measure of the amount of substance. And then again Student 4 affirmed it. Student 4 affirmed the ideas given by his/her peers. Additionally, the exchanges between peers were useful to elicit the correct concept of the mole. However, peers did not directly link the concept of the mole to the other *feedback foci* particularly to the 'visual-spatial elements of the drawing' category.

9.5.2 Cannot Identify Content

For feedback where content cannot be identified the teacher did not generate any, while peers generated several. From the researcher's point of view, all feedback episodes of the teacher on the drawings of the combination reaction carried comprehensible thoughts. The following are examples of feedback episodes from peers wherein content cannot be identified. These feedback episodes appeared to be identifying 'something' (e.g., an idea or an observation) yet it was not clear what was it.

I can feel it is the first.

It is because something happened.

(Peer-feedback from Student 1)

The event took place swiftly. We did not see what happened.

(Peer-feedback from Student 4)

The findings on the qualitative and quantitative analysis of teacher-feedback and peer-feedback in the ‘prerequisite chemistry knowledge’ and ‘cannot identify content’ categories for the combination reaction, a chemical reaction involving identity transformation, demonstrated the following characteristics of teacher-feedback and peer-feedback:

1. Teacher-feedback identified and explained (*feedback moves*) several previously learned chemistry concepts that substantiated the other *feedback foci*. Such previously learned chemistry concepts included difference between atoms, ions, and molecules; chemical behaviour of metals and nonmetals; octet rule; ionic bonding; structure of ionic compounds; and mole as a measure of the amount of substance. Peer-feedback identified (*feedback move*) a single previously learned chemistry concept, which was about the mole. Peer-feedback did not relate this concept of mole to other *feedback foci*.
2. Teacher-feedback was characterized by intelligible thoughts while peer-feedback had several episodes that had meanings the researcher cannot construe.

Chapter 10 Teacher-Feedback and Peer-Feedback on a Chemical Reaction Not Involving Identity Transformation

This chapter presents the results of the qualitative analysis of the feedback generated by the teacher and peers on the students' drawings of the decomposition reaction. This presentation of results answers the third research question for a chemical reaction not involving identity transformation: *What are the features of feedback that are valuable for supporting drawing to learn chemical reactions?* Chapter 9 presents the results for combination reaction, a chemical reaction involving identity transformation.

This chapter begins with a summary of the quantitative results on the drawings of the decomposition reaction during the intervention. Then the quantity and quality of teacher-feedback and peer-feedback in each of the four *feedback focus* categories are discussed: (1) visual-spatial elements of the drawing, (2) verbal linkages with the drawing, (3) triplet relationship and (4) prerequisite chemistry knowledge.

10.1 Quantitative Analysis of the Drawings of the Decomposition Reaction

Quantitative analysis (see Chapter 5 Teacher-feedback and peer-feedback groups' drawings during the intervention) of the drawings of the decomposition of hydrogen peroxide (H_2O_2) using manganese (IV) oxide as a catalyst (the only chemical reaction that did not involve identity transformation from reactant to products, i.e., molecular species remain molecular) revealed that:

1. the teacher-feedback group scored significantly higher than the peer-feedback group with medium effect sizes. These effect sizes were the lowest for all four types of chemical reactions.
2. both teacher-feedback and peer-feedback students had the highest quality drawings.

Quantitative and qualitative analysis of the *foci* and *moves* of teacher-feedback during the whole-class presentation and that of peer-feedback during the in-group discussion may

offer explanations for these quantitative results. The following section reports on the quantitative and qualitative analyses of the *feedback focus* on the ‘visual-spatial elements of the drawing’ category.

10.2 Feedback on Visual-Spatial Elements of the Drawing

Table 67 presents the frequency of episodes for each *feedback focus* in the teacher-feedback and peer-feedback groups for the decomposition reaction in the feedback on visual-spatial elements of the drawing.

Table 67 *Frequency of Episodes for Each Feedback Focus in the Teacher-Feedback and Peer-Feedback Groups in the ‘Visual-Spatial Elements of the Drawing’ Category for the Decomposition Reaction*

<i>Feedback focus</i>	Teacher-feedback group	Peer-feedback group
Overall quality of the drawing	4	4
Distance between particles	32	1
Arrangement of particles	15	10
Conservation of particles	60	12
Identity of the chemical species	52	25
Total	163	52

The teacher-feedback group had three times more total feedback episodes than the peer-feedback group (163 vs. 52). As discussed in Section 3.4.2 of the methodology chapter, the teacher-feedback group had more total time (40 minutes) than the peer-feedback group (30 minutes) to receive feedback. The teacher generated roughly four feedback episodes in a minute while peers generated roughly two feedback episodes in a minute. An additional 10 minutes for the peers to give/receive feedback may have caused them to generate roughly 72 total feedback episodes. This total feedback episode, however, is still less than what the teacher generated. The greater number of feedback episodes from the teacher may have provided more feedback ideas about the visual-spatial elements of the drawing. For example,

in Section 10.2.4 Distance between particles, teacher-feedback on the one hand (with 32 feedback episodes in Table 67) distinguished between the spaces of molecules of liquid (close) and gaseous (widely separated) chemical species. Peer-feedback on the other hand generated one feedback episode that incorrectly pointed out that molecules of liquid chemical species should have wide spaces between them. In effect, teacher-feedback students were supported with accurate feedback ideas about the distance between particles compared to peer-feedback students.

Furthermore, in the teacher-feedback group the two most frequent *feedback foci* were conservation of particles and identity of the chemical species. The *foci* of teacher-feedback were about the accurate representation of the Law of Conservation of Mass (or Particles) and the identity of the particles of the chemical species involved in the chemical reaction (i.e., molecules). For *feedback moves*, Figures 72 and 73 show that for conservation of particles and identity of the chemical species, the teacher often used ‘Finding out more about an idea’ and ‘Identifying an idea’. For arrangement of particles and distance between particles the teacher often used ‘Identifying an idea’ and ‘Explaining an idea’ *moves*. Across the four *feedback foci*: conservation of particles, identity of chemical species, arrangement of particles, and distance between particles, the teacher utilised the ‘Explaining an idea’ *move*. For overall quality of the drawing, the teacher often used the ‘Revising an idea’ *move*.

In giving feedback about the application of the Law of Conservation of Mass (or particles), the teacher often posed questions that sought further information. An example of this ‘Finding out more about an idea’ *move* was the teacher-feedback on the drawing of Group 6 (Figure 78) (Section 10.2.2). Additionally, the teacher provided explanations to substantiate his feedback ideas on the conservation of particles, identity of the particles of the chemical species (i.e., molecules), arrangement of particles, and distance between particles based on their phases. An example of this ‘Explaining an idea’ *move* was the teacher-

feedback on the drawing of Group 6 (Figure 74) (Section 10.2.1). Lastly in giving feedback on the overall quality of the drawing, the teacher asked students to revise the details in the drawing. An example of this ‘Revising an idea’ move was the teacher-feedback on the drawing of Group 7 (Figure 88) (Section 10.2.5).

Figure 72 Comparison Between the Teacher-Feedback and Peer-Feedback Moves Used for the Visual Elements of the Drawing of the Decomposition Reaction

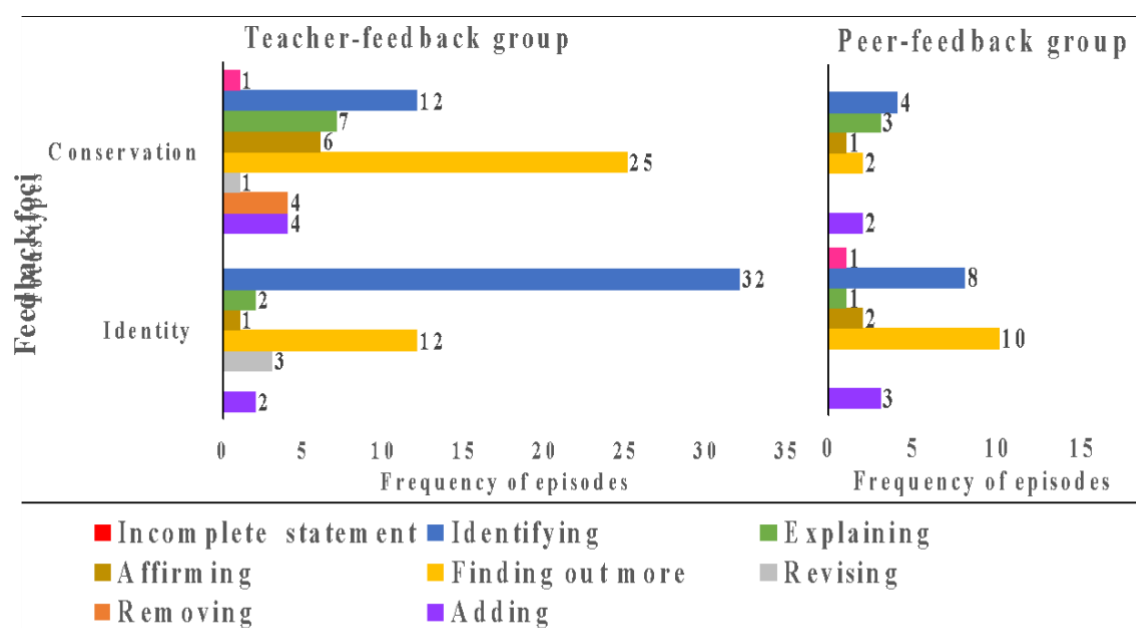
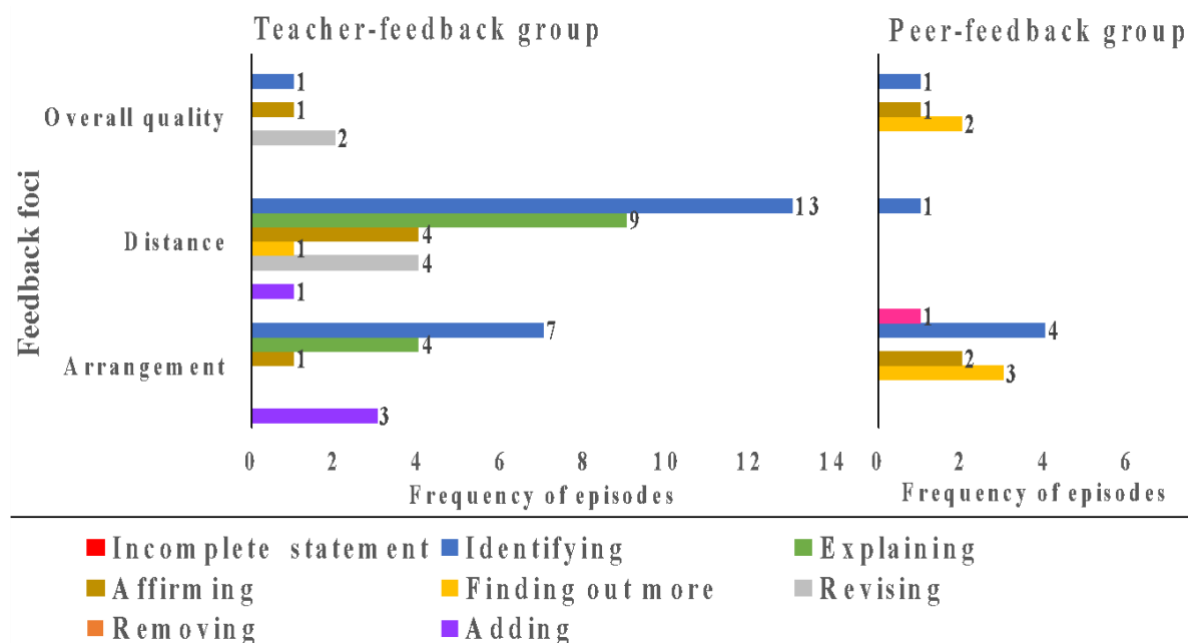


Figure 73 Comparison Between the Teacher-Feedback and Peer-Feedback Moves Used for the Spatial Elements and Overall Quality of the Drawing of the Decomposition Reaction



In the peer-feedback group, Table 67 shows that identity of the chemical species and the conservation of particles were the two most frequent *feedback foci*. Both the teacher and students' peers had the same two *feedback foci*, which were the visual elements of the drawing. For *feedback moves*, Figures 72 and 73 show that for *feedback focus* on the identity of the chemical species and arrangement of particles peers often used 'Finding out more about an idea' and 'Identifying an idea'. For the conservation of particles and distance between particles peers often used the 'Identifying an idea' move. Additionally for the identity of the chemical species and conservation of particles peers also utilised the 'Explaining an idea' move. For *feedback focus* on the overall quality of the drawing, peers often used the 'Finding out more about an idea' move.

In giving feedback about the identity of the particles of the chemical species, arrangement of the particles, and overall quality of the drawing, the students frequently asked questions that sought further information. An example of this 'Finding out more about an idea' move was the peer-feedback on the drawing of Student 5 (Figure 76) (Section 10.2.1).

Moreover, in giving feedback on the application of the Law of Conservation of Mass (or Particles) and spaces between particles based on their phases students often identified ideas. An example of this ‘Identifying an idea’ *move* was the peer-feedback on the drawing of Student 5 (Figure 79) (Section 10.2.2).

There were similarities and differences in how the two feedback groups delivered their *feedback foci* on the visual-spatial elements of the drawing. In giving *feedback focus* on the visual elements, i.e., representing the identities of the chemical species as molecules and the Law of Conservation of Mass (or Particles), both the teacher and students frequently identified feedback ideas, posed questions that sought further information, and provided explanations. Yet both groups provided fewer explanations about representing the identities of the chemical species as molecules (2 out of 52 episodes for the teacher and 1 out of 25 episodes for peers) compared to representing the Law of Conservation of Mass (or Particles) (7 out of 52 episodes for the teacher and 3 out of 25 episodes for peers). In giving feedback on the spatial elements of the drawing, i.e., arrangement and distance between particles based on their phases, the teacher identified ideas and provided explanations. Peers identified ideas and asked questions that sought further information. Lastly in giving feedback on the overall quality of the drawing the teacher frequently told students to revise their drawings while peers still posed questions that sought further information. Further examination of the quality and quantity of the feedback generated by the two groups may reveal further differences. Table 68 presents a summary of the results on the general qualitative and quantitative differences between teacher-feedback and peer-feedback in the ‘visual-spatial elements of the drawing’ category for the decomposition reaction.

Table 68 *General Qualitative and Quantitative Differences Between Teacher-Feedback and Peer-Feedback in the ‘Visual-Spatial Elements of the Drawing’ Category for the Decomposition Reaction*

Teacher-feedback	Peer-feedback
<i>Visual-spatial elements of the drawing</i>	
(a) Generated more total feedback episodes (163 episodes) than students’ peers	(a) Generated 52 total feedback episodes
(b) <i>Feedback foci</i> concentrated on the two visual elements of the drawing: conservation of particles and identity of the chemical species	(b) <i>Feedback foci</i> concentrated on the same two visual elements of the drawing
(c) For <i>feedback focus</i> on the visual elements, the teacher frequently utilised ‘Identifying an idea’ and ‘Finding out more about an idea’ as <i>feedback moves</i> . ‘Explaining an idea’ move was also used. For spatial elements, the teacher frequently utilised ‘Identifying an idea’ and ‘Explaining an idea’ <i>moves</i> .	(c) For <i>feedback focus</i> on both visual and spatial elements, students’ peers often utilised ‘Identifying an idea’ and ‘Finding out more about an idea’ as <i>feedback moves</i> . Additionally, ‘Explaining an idea’ <i>move</i> was utilised for the visual elements.
(d) For <i>feedback focus</i> on the two visual elements, the ‘Explaining an idea’ <i>move</i> was used more often for the conservation of particles than for the identity of the particles	(d) Utilised the ‘Explaining an idea’ <i>move</i> for the two visual elements like teacher-feedback

The following sections discuss further how the quality of feedback differs between the teacher-feedback and peer-feedback groups in each of the five *feedback foci* in the ‘visual-spatial elements of the drawing’ category: (a) identity of the chemical species, (b) conservation of particles, (c) arrangement of particles, (d) distance between particles, and (e) overall quality of the drawing. The quotes and exchanges of feedback episodes that were used here are from the most frequently occurring feedback ideas in the two groups. This does not mean that these were the only feedback ideas generated by either the teacher or the peers.

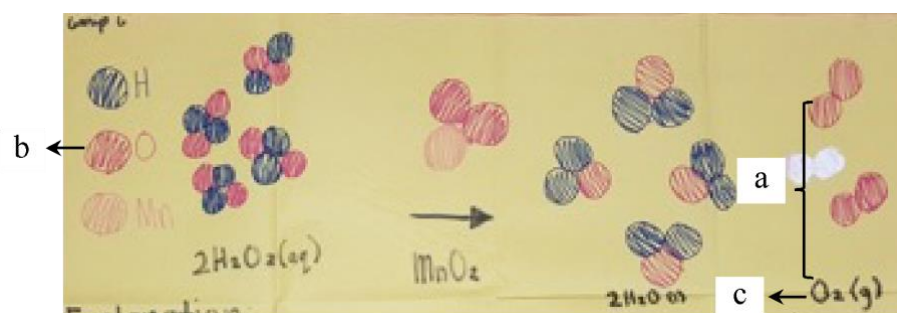
These quotes and exchanges of feedback episodes are used to highlight any similarities and differences between the quality of feedback of the two groups.

10.2.1 Identity of the Chemical Species

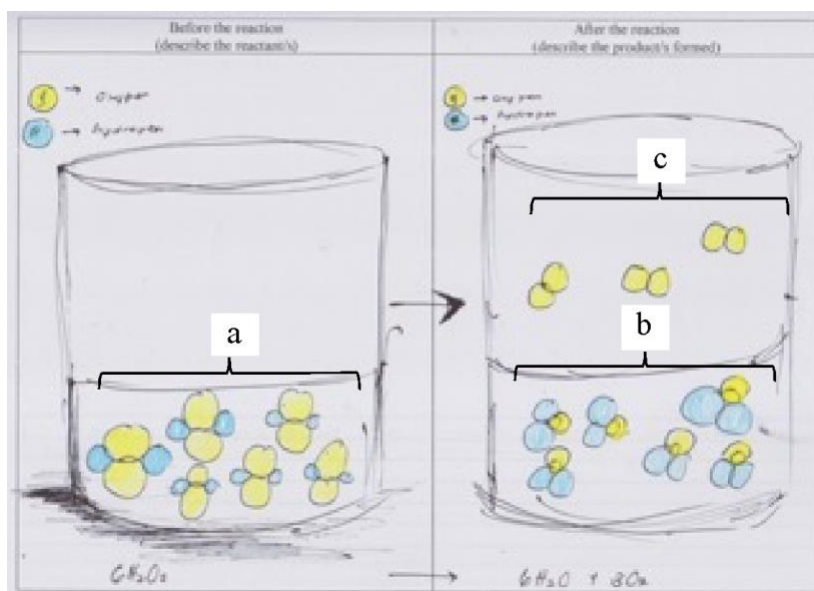
For *feedback focus* on the ‘identity of the chemical species’ teacher-feedback students appeared to know that ‘molecules’ was the accurate identity of the particles of the chemical species. Before receiving the teacher’s feedback, students correctly drew molecules as made up of bonded atoms and bearing no charges. This correct drawing of molecules is shown in the drawings of Group 6 (Figure 74) and 3 (Figure 75). However, teacher-feedback students did not explicitly write ‘molecules’ in their drawings. The teacher described the nature of the particles of the reactant (hydrogen peroxide) and products (water and oxygen) as ‘molecules’, which was a combination of two atoms (teacher’s feedback on the drawing of Group 6, Figure 74). In addition, the teacher described the property of a molecule, i.e., bears no charges (teacher’s feedback on the drawing of Group 3, Figure 75). The teacher did not say that the identity of the particles shown in the drawing of Group 3 (Figure 75) was incorrect, rather he urged students to explicitly mention ‘molecules’.

This is a molecule already (pointing at ‘a’) because two atoms of oxygen (pointing at ‘b’) combined. So, that is already a molecule (pointing at ‘a’). Two atoms of oxygen combined to form an O₂ molecule (pointing at ‘c’).

(Teacher-feedback on Group 6)

Figure 74 Group 6's Drawing

You failed to mention about the nature of the particles. So, both H_2O_2 (pointing at 'a'), water (pointing at 'b') and oxygen (pointing at 'c') are all molecules. They are all molecules. Nothing acquired charges. Nothing acquired charges during the change.
(Teacher-feedback on Group 3)

Figure 75 Group 3's Drawing

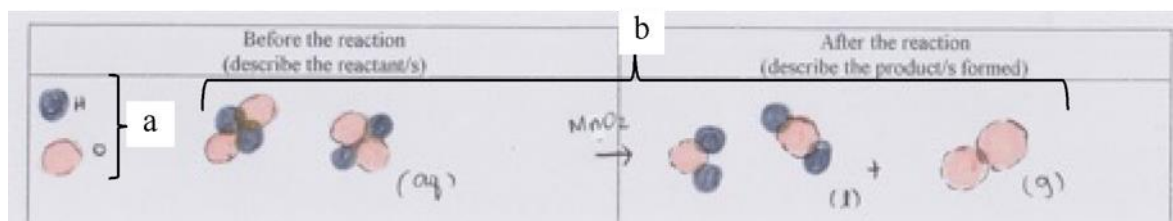
In his feedback on the drawings of Groups 6 (Figure 74) and 3 (Figure 75), the teacher shifted implicitly between using chemical formulae (O_2 molecule and H_2O_2) and technical vocabulary (water and oxygen) in naming the chemical species. Meanwhile a peer posed a

question that sought confirmation if ‘atoms’ were the correct identity of the particles of elements comprising the compounds and if ‘molecules’ are for compounds. This ‘Finding out more about an idea’ *move* is illustrated in the following peer’s feedback on the drawing of Student 5 (Figure 76). The peer was asking for confirmation if he/she should refer to oxygen and hydrogen in the legend (see ‘a’) as ‘atoms.’ And if he/she should draw hydrogen peroxide, water, and oxygen (see ‘b’) as molecules.

Are all these atoms (pointing at ‘a’)? Then, we will just draw the molecules (pointing at ‘b’)?

(Peer-feedback on Student 5)

Figure 76 *Student 5’s Drawing*

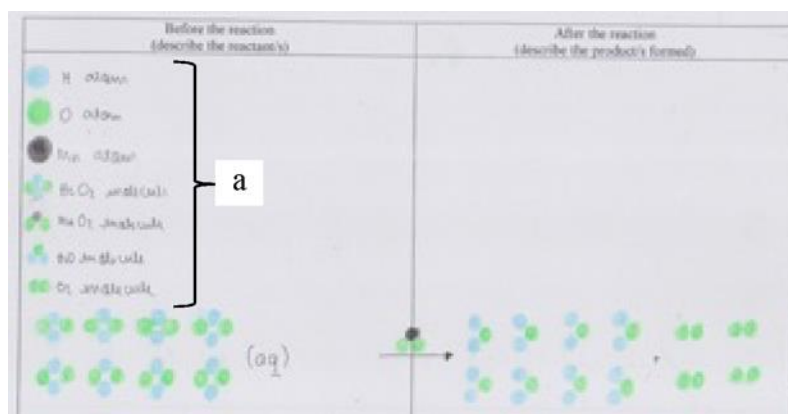


The peer appeared unsure about the identity of the particles of the chemical species and posed questions for confirmation. However, peer-feedback on another drawing showed that peer-feedback students do know the difference between atoms and molecules. This is shown in the following peer-feedback on the drawing of Student 1 (Figure 77). Peer-feedback did not precisely pinpoint which chemical species are atoms and molecules. But in the legend Student 1 correctly assigned the identity of each particle of the chemical species involved in the reaction.

Then, here at the side (pointing at 'a'), you put whether they are atoms or molecules. Here in the legend (pointing at 'a') precisely, you put if they are atoms or molecules.

(Peer-feedback on Student 1)

Figure 77 *Student 1's Drawing*



Peer-feedback however did not explicitly explain the difference between the particle identities (e.g., atoms are particles that make up an element while molecules are particles made up of two or more atoms) nor describe their property (e.g., atoms and molecules are neutral particles). Also peer-feedback did not use chemical formulae (e.g., H_2O_2 , O_2 , or H_2O) nor technical vocabulary (e.g., hydrogen peroxide, oxygen, or water) when naming the chemical species.

From the comparison of the quality of feedback of the two groups on the *feedback focus* on 'identity of the chemical species' students from both groups knew the concepts of atoms and molecules. 'By default,' students from both groups were more likely to draw particles of chemical species as atoms and molecules. This tendency of students to draw particles as atoms and molecules was also apparent in the drawings of the combination reaction (Section 9.2.1), especially in the peer-feedback group. In drawing decomposition reaction teacher-feedback students, prior to receiving feedback, accurately drew the identities

of the chemical species as atoms and molecules. Peer-feedback students, though they appeared unsure, were still able to label atoms and molecules as the accurate identities of the chemical species involved in the reaction.

The ‘inclination’ of students to represent the identity of the particles of the chemical species as atoms and molecules might explain why both teacher-feedback and peer-feedback students had the highest quality of drawing for decomposition reaction. Additionally, both the teacher and peers often delivered their feedback by identifying idea and asking questions that sought further information. Also, both the teacher and peers provided explanations in their feedback. However, the teacher had twice as many feedback episodes than peers (Table 67). This higher number of feedback episodes may have reinforced the feedback ideas slightly better for the teacher-feedback students than the peer-feedback students. Consequently, there were only medium effect sizes for the difference between the two groups quality of drawing. Both groups, before receiving feedback, ‘implicitly’ thought that atoms and molecules were the already the accurate particle identities. Table 69 presents a summary of the results on the quantitative and qualitative differences between teacher-feedback and peer-feedback *focus* on ‘identity of the chemical species’ for the decomposition reaction.

Table 69 *Quantitative and Qualitative Differences Between Teacher-Feedback and Peer-Feedback Focus on ‘Identity of the Chemical Species’ for the Decomposition Reaction*

Teacher-feedback	Peer-feedback
<i>Identity of the chemical species</i>	
(a) Generated twice as many total feedback episodes (52 episodes) than the peers	(a) Generated 25 feedback episodes
(b) Students ‘by default’ tend to represent the identity of the particles as ‘atoms’ and ‘molecules’	(b) Same as teacher-feedback students: ‘by default’, peer-feedback students tend to represent the identity of the particles as ‘atoms’ and ‘molecules’

(c) Often utilised ‘Identifying an idea’ and ‘Finding out more about an idea’ as <i>feedback moves</i> . Also utilised the ‘Explaining an idea’ <i>move</i> .	(c) Often utilised the same two <i>feedback moves</i> as teacher-feedback, i.e., ‘Identifying an idea’ and ‘Finding out more about an idea’. Also utilised the ‘Explaining an idea’ <i>move</i> .
(d) Commented on making explicit that ‘atoms’ and ‘molecules’ are the identity of the particles. Also identified the property of atoms and molecules, i.e., no charges.	(d) A peer posed questions that sought confirmation of the identities of the particles. Did not explicitly mention about the property (i.e., no charges) of atoms and molecules.
(e) Used chemical formulae and technical vocabulary in naming the chemical species, although switching between chemical formulae and technical vocabulary was implicit	(e) Did not use chemical formulae nor technical vocabulary in naming the chemical species

10.2.2 Conservation of Particles

For the *feedback focus* on ‘conservation of particles’, the teacher often posed questions that sought further information from the students. Those questions were used to focus students’ attention and thinking towards the number of particles of each chemical species in the reaction. In the following drawing of Group 6 (Figure 78), the team incorrectly drew two additional oxygen atoms or one oxygen molecule (see ‘d’). After directing the team’s attention to the error through a series of questions, the teacher explained how to accurately show the Law of Conservation of Mass (or Particles) in the drawing. The teacher pointed out the correct ratio of molecules, i.e., 2 molecules of hydrogen peroxide: 2 molecules of water: 1 molecule of oxygen. These ‘Finding out more about an idea’ then ‘Explaining an idea’ *moves* are illustrated in the following exchanges between Student 1 of Group 6 and the teacher while giving feedback on the team’s drawing (Figure 78):

Teacher: How many oxygen atoms (see ‘a’) do you have on the reactant side (pointing at ‘b’)? How many oxygen atoms there on the reactant side? The left side of the equation?

Student 1: Eight.

Teacher: Eight. Two, four, six, eight. How many there on the product side (pointing at 'c')? Right side? How many?

Student 1: 10.

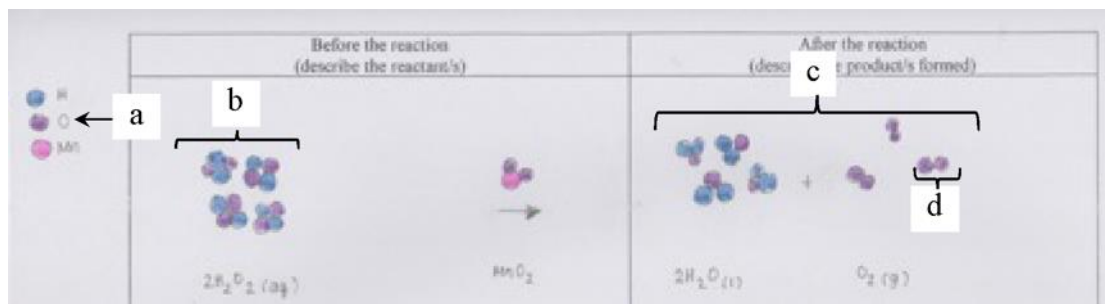
Teacher: 10. So therefore the conservation of atoms was violated. So where do those two atoms of oxygen (pointing at 'd') come from?

Student 1: We need to remove ahh. Okay.

Teacher: Because no matter how many atoms you add, the ratio of the numbers of molecules you added remains the same, 2 2 1.

(Teacher-feedback on Group 6)

Figure 78 *Group 6's Drawing*



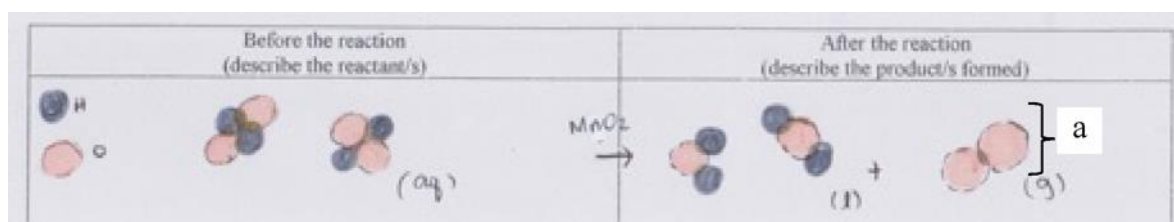
Towards the last part of the conversation the teacher implicitly switched from conserving 'atoms' to conserving 'molecules.' The teacher started looking at the unequal number of atoms in the reactant and product sides then switched to pointing out the correct ratio of molecules (2:2:1). In the peer-feedback group Student 5, before receiving feedback, had accurately represented the Law of Conservation of Mass (or Particles) in his/her drawing (Figure 79). A peer's feedback was focused on adding more molecules of both the reactants and products while keeping the same ratio between them as Student 5 originally drawn. This

‘Adding a detail’ *feedback move* is illustrated in the following peer’s feedback on the drawing of Student 5 (Figure 79).

It should be accurate with our idea, therefore there should be many molecules. But it should still be equal to the ratio of molecules (i.e., 2:2:1) that we have in our sketch.

(Peer-feedback on Student 5)

Figure 79 *Student 5’s Drawing*



The teacher generated five times more feedback episodes (60 vs.12) than the peers (Table 67). Roughly 42% (25 episodes) of these teacher-feedback episodes were delivered via ‘Finding out more about an idea’ *move*. This portion of teacher-feedback episodes delivered via ‘Finding out more about an idea’ *move* was greater than the total peer-feedback episodes (12 episodes, Table 67). Such a greater number of teacher-feedback episodes was attributed to the teacher’s use of questions (or series of questions) to focus students’ thoughts on accurately representing the Law of Conservation of Mass (or Particles). Also, such a greater number of feedback episodes may have reinforced the ideas of particle conservation better for the teacher-feedback group since they had a more cognitive engagement with it. In fact, 91% of teacher-feedback students while only 73% of peer-feedback students accurately drew the conservation of both hydrogen and oxygen particles.

A student in the peer-feedback group appeared to know how to draw the Law of Conservation of Mass (or Particles) before receiving feedback. A peer pointed out the need to

add more molecules of the chemical species. This peer was probably considering how to correctly show the phases of the chemical species. For example, oxygen gas did appear gaseous because it was drawn as a single molecule (see ‘a’ from Student 5’s drawing, Figure 79). Adding more oxygen molecules with wide empty spaces between each other would better show it as a gas. The peer noted that when adding more molecules the correct ratio in the chemical reaction should be followed. Table 70 presents a summary of the results on the quantitative and qualitative differences between teacher-feedback and peer-feedback *focus* on ‘conservation of particles’ for the decomposition reaction.

Table 70 *Quantitative and Qualitative Differences Between Teacher-Feedback and Peer-Feedback Focus on ‘Conservation of Particles’ for the Decomposition Reaction*

Teacher-feedback	Peer-feedback
<i>Conservation of particles</i>	
(a) Generated five times more total feedback episodes (60 episodes) than the peers	(a) Generated 12 feedback episodes
(b) Prior to feedback, the Law of Conservation of Mass (or Particles) was not drawn	(b) Prior to feedback, the Law of Conservation of Mass (or Particles) was drawn
(c) Often utilised ‘Finding out more about an idea’, ‘Identifying an idea’ and ‘Explaining an idea’ as <i>feedback moves</i>	(c) Often utilised similar <i>feedback moves</i> as teacher-feedback: ‘Identifying an idea’, ‘Explaining an idea’ and ‘Finding out more about an idea’
(d) Posed questions to focus students’ attention and thoughts towards the incorrect number of particles. Subsequently, the teacher explained the correct ratio between the molecules.	(d) A peer pointed out that more molecules of each chemical species should be added while keeping the same ratio between them

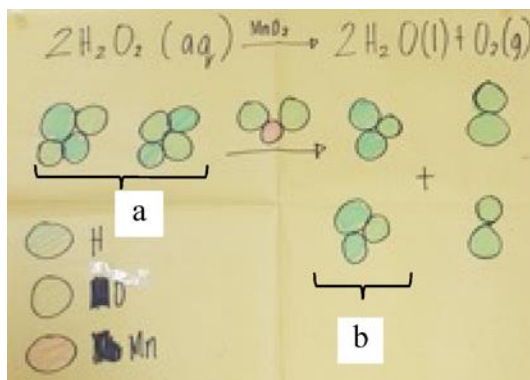
10.2.3 Arrangement of Particles

For *feedback focus* on the ‘arrangement of particles’ the teacher pointed out that particles of the reactant (hydrogen peroxide) and a product (water), which were both liquids, should be drawn as dispersed. This ‘Identifying an idea’ *feedback move* is illustrated in the following teacher’s feedback on the drawing of Group 8 (Figure 80).

The liquid (pointing at ‘b’) and the aqueous (pointing at ‘a’). They (‘a’ and ‘b’) all are dispersed.

(Teacher-feedback on Group 8)

Figure 80 Group 8’s Drawing

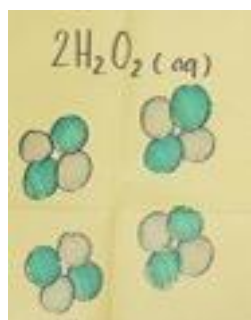


Nonetheless the teacher did not explicitly identify that the dispersion of particles should be irregular. It was pertinent to point out that particles should be dispersed irregularly because students drew them as regularly dispersed (see drawings of Group 8, Figure 80 and Group 4, Figure 81). Additionally, the teacher explained that hydrogen peroxide particles could be drawn with water molecules surrounding them to show that it was an aqueous solution. This ‘Explaining an idea’ *feedback move* is illustrated in the following teacher’s feedback on the drawing of Group 4 (Figure 81).

Since hydrogen peroxide is liquid dissolved in another liquid, water. It is in an aqueous solution. Speaking at the submicroscopic level, the H_2O_2 is surrounded by water molecules.

(Teacher-feedback on Group 4)

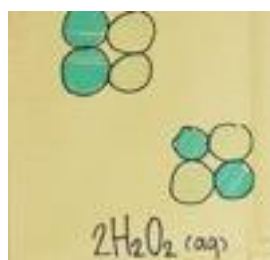
Figure 81 *Group 4's Drawing of Hydrogen Peroxide Solution*



In the teacher's feedback on the drawing of Group 4 (Figure 81) the teacher made explicit his shift from one descriptive level to another. The teacher started at the macroscopic level by describing hydrogen peroxide as a liquid dissolved in another liquid. Then he moved to the submicroscopic and symbolic levels. He told students that at the submicroscopic level, H_2O_2 is surrounded by water molecules. The teacher also urged students to add more molecules of hydrogen peroxide to better represent its arrangement (i.e., dispersion of particles) as an aqueous solution. This 'Adding a detail' *feedback move* is illustrated in the following teacher's feedback on the drawing of Group 5 (Figure 82).

You add some more molecules of H_2O_2 so that you can represent the arrangement of the particles.

(Teacher-feedback on Group 5)

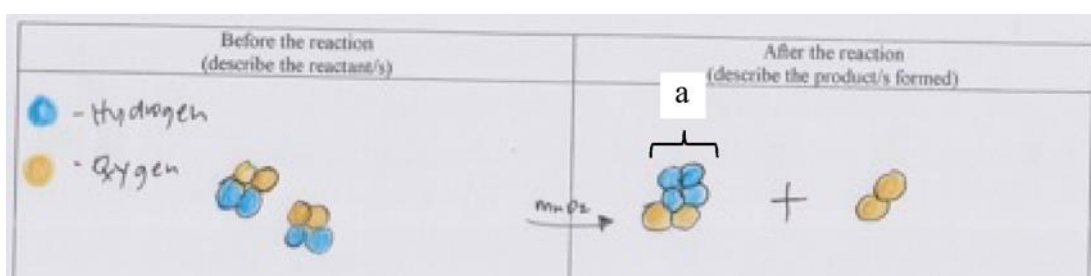
Figure 82 *Group 5's Drawing of Hydrogen Peroxide Solution*

A peer (Student 1) identified that water molecules, one of the products, should be drawn as dispersed molecules and not as stacked above each other. Drawing water as dispersed molecules correctly represented it as a liquid and not as a solid. Yet the peer did not explicitly point out that dispersion should be irregular. This 'Identifying an idea' *feedback move* is illustrated in the following peer's feedback on the drawing of Student 3 (Figure 83).

Then, your H₂O (pointing at 'a') should be separated. Two blues together with one green.

Is that green? (The colour is orange. Student 1 has a colour vision deficiency)

(Peer-feedback on Student 3)

Figure 83 *Student 3's Drawing*

The same peer (Student 1) gave feedback on another drawing by posing a question that sought further information on whether water molecules should be drawn surrounding hydrogen peroxide molecules. Drawing hydrogen peroxide molecules surrounded by water molecules represented it as an aqueous solution. Posing a question in this case was productive

because it led the student to accurately draw hydrogen peroxide as an aqueous solution. This ‘Finding out more about an idea’ *feedback move* is shown in the following exchanges between Students 4 and 1 while looking at the drawing of Student 4 (Figure 84).

Student 4: Is it correct to draw H_2O (molecules)?

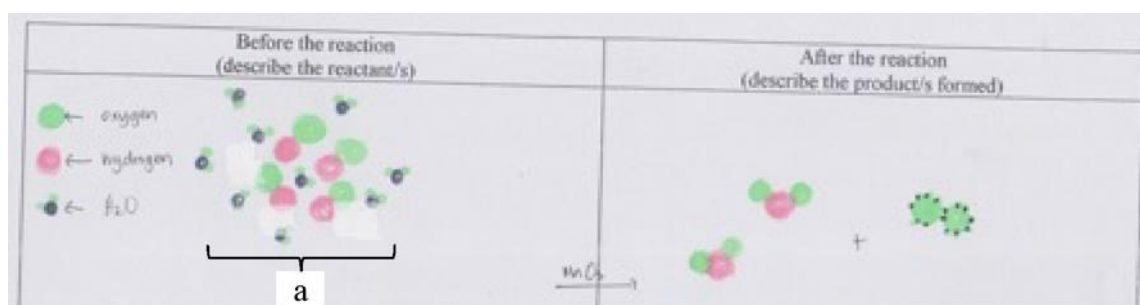
Student 1: I don’t know * that solution. We should be the same. Does it (hydrogen peroxide solution, ‘a’) have H_2O (molecules)?

Student 4: Because that is aqueous *.

(Peer-feedback on the drawing of Student 4)

*Incomprehensible

Figure 84 Student 4’s Drawing



Quantitatively, both feedback groups had almost the same frequency of feedback episodes (15 vs. 10) (Table 67). The amount of feedback received might not have had an impact on the quality of drawings. Qualitatively teacher-feedback and peer-feedback exhibited similarities and differences in their *feedback focus* on the ‘arrangement of particles’. Both assessors pointed out that molecules should be dispersed. Also, both assessors did not explicitly mention that such dispersion should be irregular. Lastly both assessors identified that hydrogen peroxide being an aqueous solution should be drawn as surrounded by water molecules. Teacher-feedback indicated that more molecules of hydrogen

peroxide should be drawn to better show its dispersion. Peer-feedback, on the other hand, did not ask to draw more molecules of hydrogen peroxide. It was more likely that teacher-feedback students were prompted to accurately show the dispersion of particles not only for hydrogen peroxide but also for the other chemical species, which were also fluids (i.e., liquid water and oxygen gas).

The teacher and the peer utilised distinct *feedback moves*. The teacher, on the one hand, identified the dispersion of hydrogen peroxide molecules and explained drawing water molecules surrounding hydrogen peroxide molecules. In explaining the teacher was explicit on his shift from one descriptive level to another (macroscopic to submicroscopic). The peer, on the other hand, identified the dispersion of particles and asked a question that sought additional information about whether water molecules should be drawn around hydrogen peroxide molecules. Question-posing by the peer led to the accurate arrangement of hydrogen peroxide particles as an aqueous solution. Table 71 presents a summary of the results on the quantitative and qualitative differences between teacher-feedback and peer-feedback *focus* on the ‘arrangement of particles’ for the decomposition reaction.

Table 71 *Quantitative and Qualitative Differences Between Teacher-Feedback and Peer-Feedback Focus on the ‘Arrangement of Particles’ for the Decomposition Reaction*

Teacher-feedback	Peer-feedback
<i>Arrangement of particles</i>	
(a) Generated 15 feedback episodes	(a) Generated 10 feedback episodes
(b) Often utilised ‘Identifying an idea’ and ‘Explaining an idea’ as <i>feedback moves</i>	(b) Often utilised ‘Identifying an idea’ and ‘Finding out more about an idea’ as <i>feedback moves</i>
(c) Identified that hydrogen peroxide (reactant) and water (product) molecules were dispersed. But did not explicitly identify that dispersion should be irregular.	(c) Identified that water molecules were dispersed and not stacked above each other. But (like teacher-feedback) did not

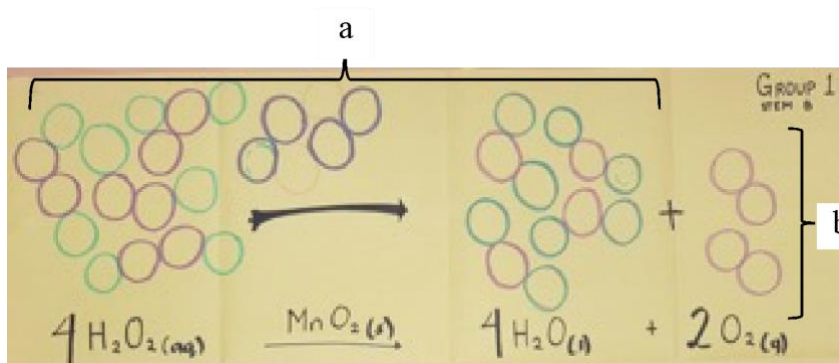
	explicitly identify that dispersion was irregular.
(d) Explained that hydrogen peroxide molecules should be drawn as surrounded by water molecules. While explaining there was an explicit shift of descriptive levels (from macroscopic to submicroscopic).	(d) Posed a question on whether hydrogen peroxide molecules should be drawn as surrounded by water molecules. Question-posing was productive because it led to the accurate arrangement of hydrogen peroxide molecules.
(e) Identified that more hydrogen peroxide molecules should be added to better represent dispersion	(e) Did not identify that more molecules of the chemical species should be added to better represent dispersion

10.2.4 Distance Between Particles

Prior to feedback the drawings in the teacher-feedback group almost always represented the spaces between molecules of liquid (hydrogen peroxide and water) and gaseous (oxygen) chemical species as comparable. Hence it was difficult to distinguish between the two phases. The teacher then explained that to distinguish between the two phases either the spaces between gaseous particles should be wider than the spaces between liquid particles or the spaces between liquid particles should be closer than the spaces between gaseous particles. In the following teacher's feedback on the drawing of Group 1 (Figure 85), the teacher identified that oxygen was a gas and therefore should have molecules separated with wide empty spaces compared to liquid particles.

Oxygen is a gas therefore they are more separated than that (pointing at 'b'). Because if you will compare the distance between the two oxygen molecules, it is comparable to the spaces in the liquid state (pointing at 'a').

(Teacher-feedback on Group 1)

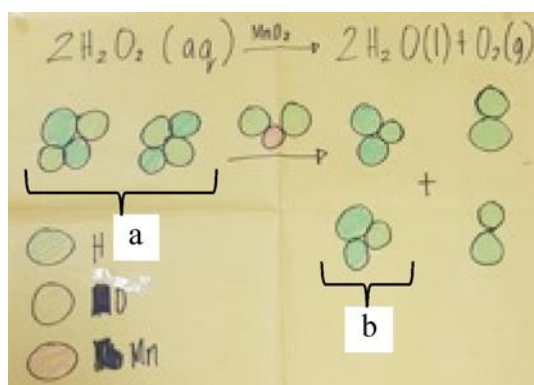
Figure 85 Group 1's Drawing

In the following teacher's feedback on the drawing of Group 8 (Figure 86), the teacher pointed out that hydrogen peroxide and water were liquids, therefore they should have molecules that were closer compared to the gaseous molecules.

We assumed that is a liquid (pointing at 'a') so therefore the molecules are quite closer.

Also, with water (pointing at 'b'), keep it closer.

(Teacher-feedback on Group 8)

Figure 86 Group 8's Drawing

Peers in their only feedback episode identified that liquid particles should have wide spaces between them. This feedback resulted in drawings where the spaces between liquid molecules (hydrogen peroxide and water) were greater compared to gaseous molecules

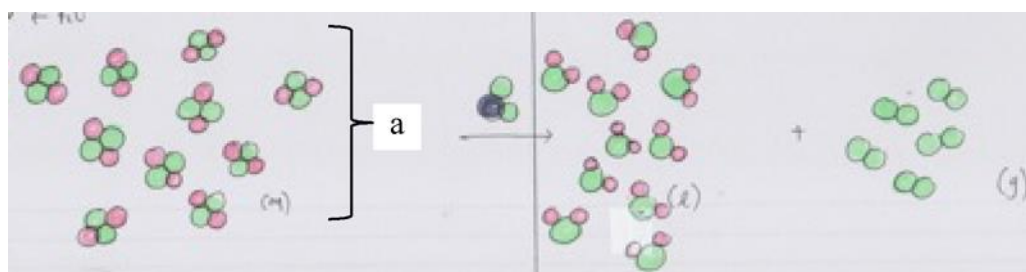
(oxygen). An incorrect distinction was made between the two phases. This ‘Identifying an idea’ *feedback move* is illustrated in the following peer’s feedback which resulted in the drawing of Student 4 (Figure 87):

Hydrogen peroxide should be somehow widely separated * (see ‘a’)

(Peer-feedback on Student 4)

*Incomprehensible

Figure 87 *Student 4’s Drawing*



Teacher-feedback supported the accurate drawing of the distance between particles of the chemical species involved in the decomposition reaction. The teacher explained the correct distinction between liquid and gaseous molecules in terms of spaces between particles while students’ peers did not. Moreover, the teacher generated a greater number of feedback episodes than the peers (32 vs. 1) (Table 67) which may have espoused those accurate feedback ideas better for the teacher-feedback students. Table 72 presents a summary of the results on the quantitative and qualitative differences between teacher-feedback and peer-feedback *focus* on the ‘distance between particles’ for the decomposition reaction.

Table 72 *Quantitative and Qualitative Differences Between Teacher-Feedback and Peer-Feedback Focus on the ‘Distance Between Particles’ for the Decomposition Reaction*

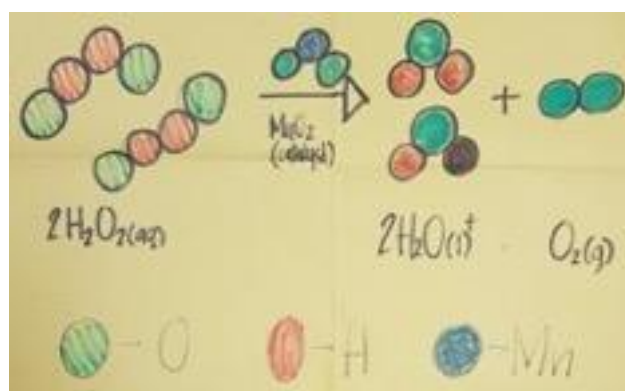
Teacher-feedback	Peer-feedback
<i>Distance between particles</i>	
(a) Generated more total feedback episodes (32 episodes) than the peers	(a) Generated one feedback episode
(b) Accurately explained the distance between molecules of liquid and gaseous chemical species	(b) Pointed out that molecules of liquid chemical species should have wide spaces between them. This resulted to an inaccurate distance between liquid and gaseous molecules
(c) Often utilised ‘Identifying an idea’ and ‘Explaining an idea’ as <i>feedback moves</i>	(c) Utilised ‘Identifying an idea’ as the only <i>feedback move</i>

10.2.5 Overall Quality of the Drawing

For *feedback focus* on the ‘overall quality of the drawing’, the teacher gave feedback to the drawing in general after giving feedback on specific aspects of it (e.g., the identity of the particles and chemical equation). The teacher told students to revise the drawings based on their learning from the previous sessions of the intervention. This ‘Revising an idea’ *feedback move* is illustrated in the following teacher’s feedback on the drawing of Group 7 (Figure 88).

Okay so, I think a little bit to revise on your sketch because you learned concepts from the past worksheets.

(Teacher-feedback on Group 7)

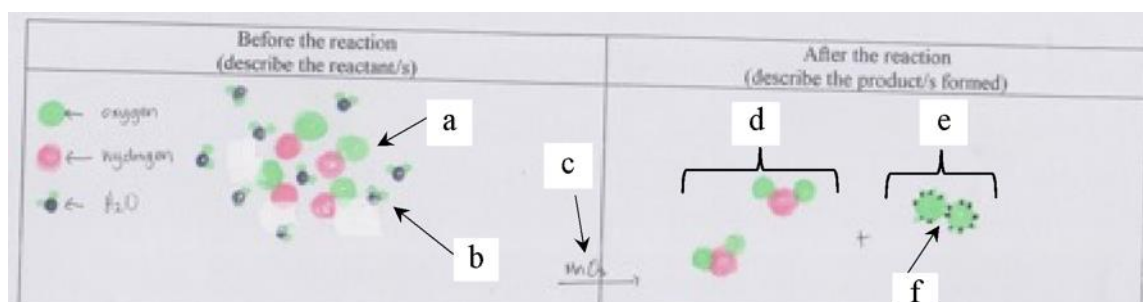
Figure 88 Group 7's Drawing

A peer when asked to give feedback on a drawing, posed a question expressing uncertainty on which aspects of the drawing were accurate. This ‘Finding out more about an idea’ *feedback move* is illustrated in the following exchange between Students 4 and 1 on the drawing of Student 4 (Figure 89). Student 4 presented his/her drawing while Student 1 gave feedback by posing the question.

Student 4: In my sketch, this is what I did. Here, I have H_2O_2 (pointing at ‘a’). Since this is aqueous, so I drew water. It has H_2O (pointing at ‘b’). Then, here is the catalyst (pointing at ‘c’). Finally, here is H_2O (pointing at ‘d’) and two O_2 (pointing at ‘e’). It has dots (pointing at ‘f’) because it is a compound. Is that right? Is it a compound? They were (oxygen atoms) sharing electrons to keep O_2 stable.

Student 1: I do not know what to say. Which aspects of our work were accurate?

(Peer-feedback on Student 4)

Figure 89 *Student 4's Drawing*

Quantitatively both the teacher and peers generated the same amount of feedback episodes (4 vs. 4, Table 67). Hence the number of feedback episodes may have had no impact on the quality of drawings. Qualitatively teacher-feedback about the overall quality of the drawing tried to link students' prior learning to the current task. Whereas peer-feedback was an expression of the student's uncertainty for their feedback ideas. Table 73 presents a summary of the results on the quantitative and qualitative differences between teacher-feedback and peer-feedback *focus* on the 'overall quality of the drawing' for the decomposition reaction.

Table 73 *Quantitative and Qualitative Differences Between Teacher-Feedback and Peer-Feedback Focus on the 'Overall Quality of the Drawing' for the Decomposition Reaction*

Teacher-feedback	Peer-feedback
<i>Overall quality of the drawing</i>	
(a) Generated four feedback episodes	(a) Generated the same number of feedback episodes as the teacher
(b) Frequently used 'Revising an idea' as <i>feedback move</i>	(b) Frequently used 'Finding out more about an idea' as <i>feedback move</i>
(c) Used feedback to prompt students to apply what they learned from their previous drawing tasks	(c) Posed a question that expressed uncertainty about the quality of the drawing

The results on the qualitative and quantitative analysis of the teacher-feedback and peer-feedback in the ‘visual-spatial elements of the drawing’ category for the decomposition reaction, the only chemical reaction not involving identity transformation, demonstrated the following characteristics of teacher-feedback and peer-feedback:

1. Both teacher-feedback and peer-feedback identified that ‘atoms’ and ‘molecules’ were the accurate identities of the chemical species. More so both feedback groups appeared to instinctively know that ‘atoms’ and ‘molecules’ were the accurate identity of the particles.
2. Both teacher-feedback and peer-feedback pointed out the accurate application of the Law of Conservation of Mass (or Particles) in the drawings.
3. Both teacher-feedback and peer-feedback recognised that liquid molecules were drawn as scattered particles. Both sources of feedback were implicit in pointing out that liquid molecules were scattered irregularly.
4. Both teacher-feedback and peer-feedback identified that hydrogen peroxide molecules were drawn as surrounded with water molecules to show that it was an aqueous solution.
5. Posing questions that sought further information as a *feedback move* was productive for both teacher-feedback and peer-feedback because it led to accurate ideas for the drawings. The teacher utilised series of questions to direct students’ attention and thoughts towards the application of the Law of Conservation of Mass (or Particles) in the drawings. A peer asked a question to support the accurate drawing of hydrogen peroxide as an aqueous solution, i.e., hydrogen peroxide molecules surrounded with water molecules.
6. Both teacher-feedback and peer-feedback provided explanations to substantiate *feedback focus* on the visual elements of the drawing: identity of the chemical species

and conservation of particles. However, only teacher-feedback provided explanations for *feedback focus* on the spatial elements of the drawing: arrangement of particles and distance between particles.

7. The teacher generated more feedback episodes than the peers across *feedback focus* on the visual and spatial elements of the drawing, while the teacher and peers generated equal number of feedback episodes for *feedback focus* on the overall quality of the drawing.
8. Teacher-feedback identified explicitly the property of the particles (i.e., atoms and molecules do not bear charges) while peer-feedback did not.
9. Teacher-feedback utilised the correct chemical formulae and technical/canonical vocabulary in identifying the chemical species involved in the reaction while peer-feedback did not.
10. Teacher-feedback made explicit the shift from macroscopic to submicroscopic level in giving feedback on the arrangement of particles; peer-feedback did not demonstrate such shift of descriptive levels.
11. Teacher-feedback pointed out that more molecules of each chemical species should be added to better represent the dispersion of particles based on phases. Peer-feedback did not recognise this idea of adding more molecules of each chemical species.
12. Teacher-feedback made accurate distinction on the spaces between molecules of liquid (close) and gaseous (widely separated) chemical species. Peer-feedback inaccurately pointed out that molecules of liquid chemical species have wide spaces between them. As a result, a peer-feedback student made an incorrect distinction between liquid and gaseous molecules.

The following section presents the quantitative and qualitative analysis of the *feedback focus* on the ‘verbal linkages with the drawing’ category.

10.3 Feedback on Verbal Linkages with the Drawing

Table 74 presents the frequency of episodes for each *feedback focus* in the teacher-feedback and peer-feedback groups for the decomposition reaction in the ‘verbal linkages with the drawing’ category.

Table 74 *Frequency of Episodes for Each Feedback Focus in the Teacher-Feedback and Peer-Feedback Groups in the ‘Verbal Linkages with the Drawing’ Category for the Decomposition Reaction*

<i>Feedback focus</i>	Teacher-feedback group	Peer-feedback group
Written description of the drawing	10	4
Oral presentation	0	0
Total	10	4

Table 74 shows that the teacher gave more than twice total feedback episodes than the peers (10 vs. 4). The teacher generated two feedback episodes in eight minutes while peers generated two feedback episodes in 15 minutes. Hence an additional 10 minutes for the peers could not have generated additional feedback episodes to match that of the teacher. The greater number of feedback episodes from the teacher may suggest that he generated more feedback ideas and used additional *feedback moves* than the peers. Also, here in the decomposition reaction (like in the combination reaction), the ‘verbal linkages with the drawing’ category had the least number of feedback episodes. Both the teacher and peers still did not give much feedback about how words (written or oral) were utilised to communicate the submicroscopic ideas in the drawing. Both groups recognised the use of written rather than oral words to support communication of the submicroscopic ideas in the drawing.

In the teacher-feedback group feedback was only given on the ‘written description of the drawing’. There was no feedback focused on the ‘oral presentation’. For *feedback moves*, Figure 90 shows that for the ‘written description of the drawing’, the teacher frequently

utilised ‘Identifying an idea’ and ‘Revising an idea’. Teacher-feedback focused on the written explanation that students used to describe their drawings. In delivering the feedback the teacher often identified ideas and asked students to revise details. Examples of these ‘Identifying an idea’ and ‘Revising an idea’ *feedback moves* are presented in Section 10.3.1.

Figure 90 Comparison Between the Teacher-Feedback and Peer-Feedback Moves Used in the ‘Verbal Linkages with the Drawing’ Category for the Decomposition Reaction

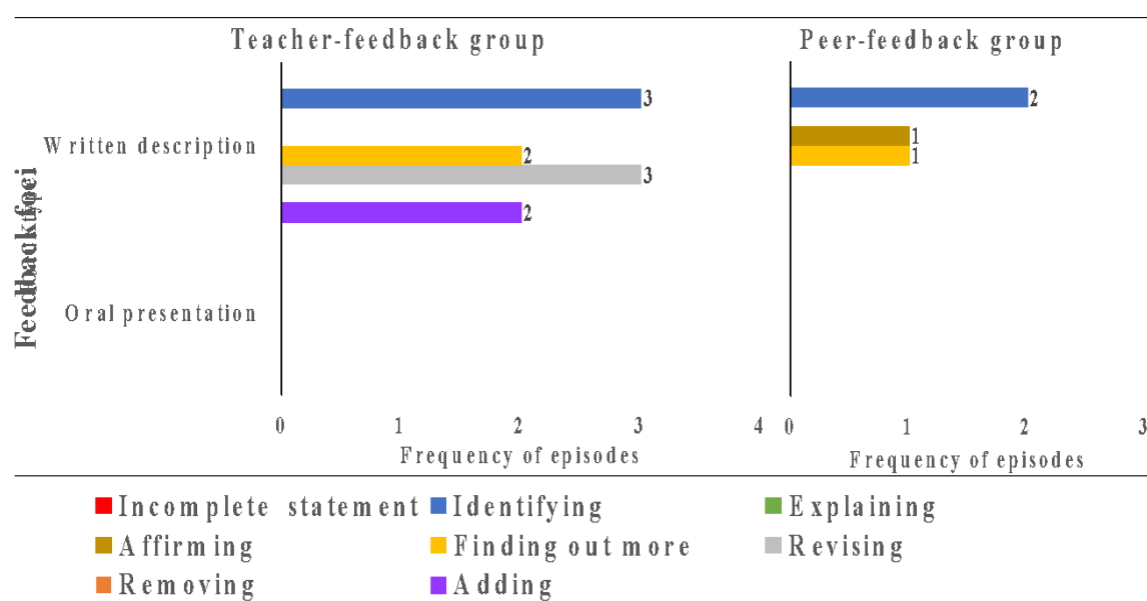


Table 74 also shows that the peer-feedback group gave feedback only on the ‘written description of the drawing’. There was also no feedback focused on the ‘oral presentation’. For *feedback moves*, Figure 90 shows that peers frequently used the ‘Identifying an idea’. The *focus* of peer-feedback was also on the written explanation that students used to describe their drawings. In delivering such feedback students often identified ideas. An example of this ‘Identifying an idea’ *move* is presented in Section 10.3.1.

For the verbal elements associated with the drawing both the teacher and peers were concerned only with the written (and not the oral) explanation of the drawings. The teacher, on the one hand, delivered feedback about the written description via identification of ideas

and revision of details. Peers on the other hand, identified ideas. Table 75 presents a summary of the results on the general quantitative and qualitative differences between teacher-feedback and peer-feedback in the ‘verbal linkages with the drawing’ category for the decomposition reaction.

Table 75 *General Quantitative and Qualitative Differences Between Teacher-Feedback and Peer-Feedback in the ‘Verbal Linkages with the Drawing’ Category for the Decomposition Reaction*

Teacher-feedback	Peer-feedback
<i>Verbal linkages with the drawing</i>	
(a) Generated more total feedback episodes (10 episodes) than the students’ peers	(a) Generated four feedback episodes
(b) Focused on the written description of the drawing	(b) Focused also on the written description of the drawing
(c) Frequently utilised ‘Identifying an idea’ and ‘Revising an idea’ as <i>feedback moves</i>	(c) Frequently utilised ‘Identifying an idea’ as <i>feedback move</i>
(d) Had no feedback on the oral presentation of the drawing	(d) Also had no feedback on the oral presentation of the drawing

The following section further describes the quality of feedback ideas from the teacher-feedback and peer-feedback groups for the written description of the drawing.

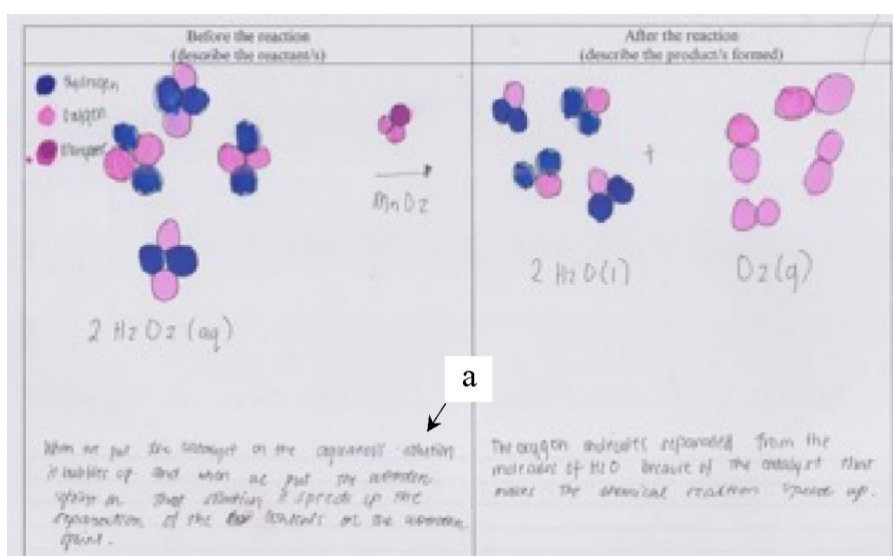
10.3.1 Written Description of the Drawing

For feedback focused on the ‘written description of the drawing’ the teacher checked if the information in the written description was complete. In the following teacher’s feedback on the written description of Group 6’s drawing (Figure 91), the teacher posed a question about the name of the aqueous solution being referred to in the written description. The name of the aqueous solution was not stated in the written description. The teacher then identified that it was hydrogen peroxide.

In your explanation, the aqueous solution of what (pointing at 'a')? The aqueous solution of hydrogen peroxide. It is not there. The aqueous solution of hydrogen peroxide.

(Teacher-feedback on Group 6)

Figure 91 Group 6's Drawing

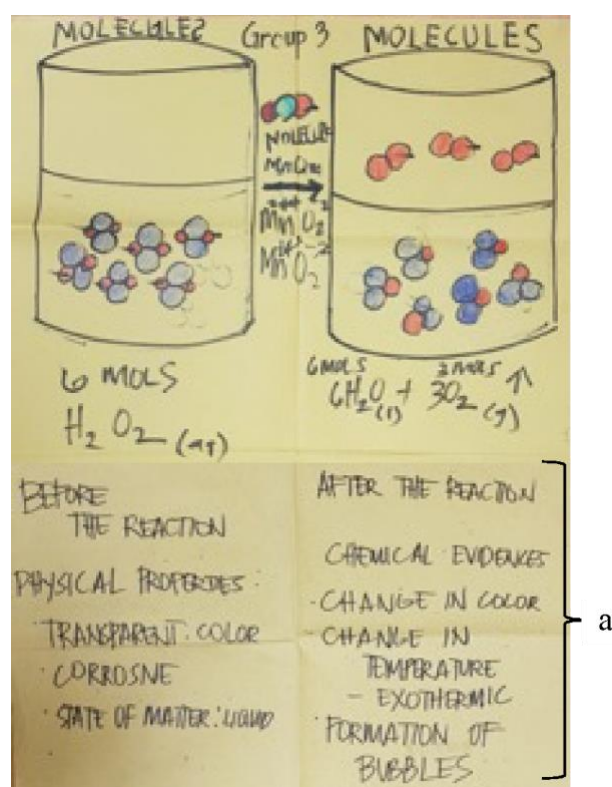


Additionally, the teacher pointed out that the written description should be about the submicroscopic ideas in the drawing and not on the macroscopic observations from the practical work. Observations from the practical work were supposed to be written as answers to the guide questions in a separate portion of the worksheet. Consequently, the teacher asked the students to revise their written description. This 'Revising an idea' move is illustrated in the following teacher's feedback on the drawing of Group 3 (Figure 92).

The (macroscopic) *observations* are placed in the proper column. Only the *reaction* itself should be placed there (pointing at 'a'). Kindly revise that or modify that.

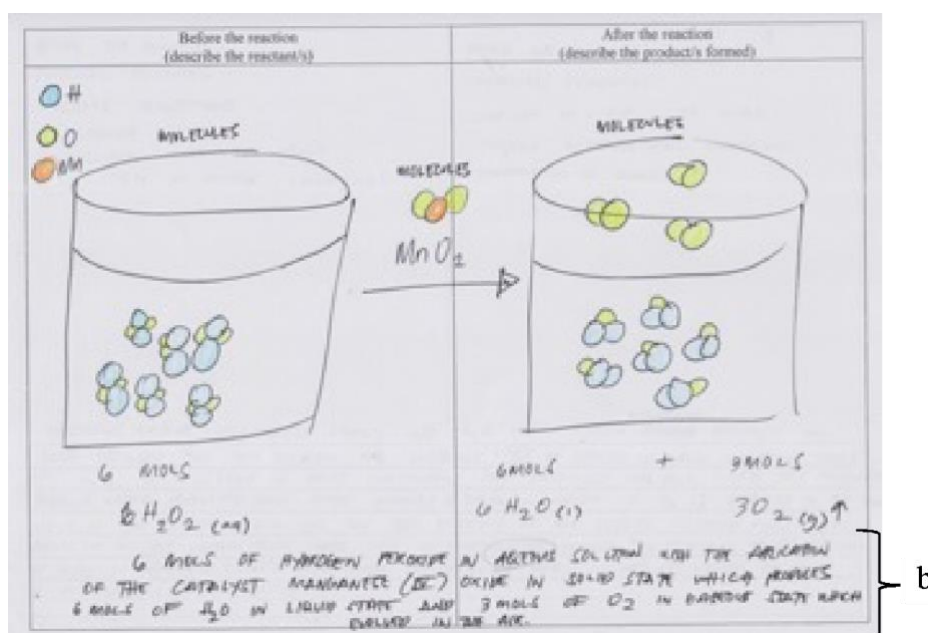
(Teacher-feedback on Group 3)

Figure 92 Group 3's Drawing and Written Description



In the feedback on the drawing of Group 3 (Figure 92), the teacher referred to the submicroscopic ideas about the chemical reaction as ‘reaction’. This could be surmised from the changes made in the written description of Group 3 (see ‘b’, Figure 93). The student from Group 3 wrote about the submicroscopic ideas after receiving the teacher-feedback.

Figure 93 Revised Drawing and Written Description of a Group 3 Student



A peer in his/her feedback focused on the ‘written description of the drawing’ identified that the description below the drawing (see ‘c’) should specify that the aqueous solution is hydrogen peroxide. Hydrogen peroxide was drawn as surrounded by water molecules. This ‘Identifying an idea’ *feedback move* is illustrated in the following exchanges between Students 4 and 1 while looking at the drawing of Student 4 (Figure 94).

Student 4: Is it correct to draw H_2O (pointing at ‘a’)?

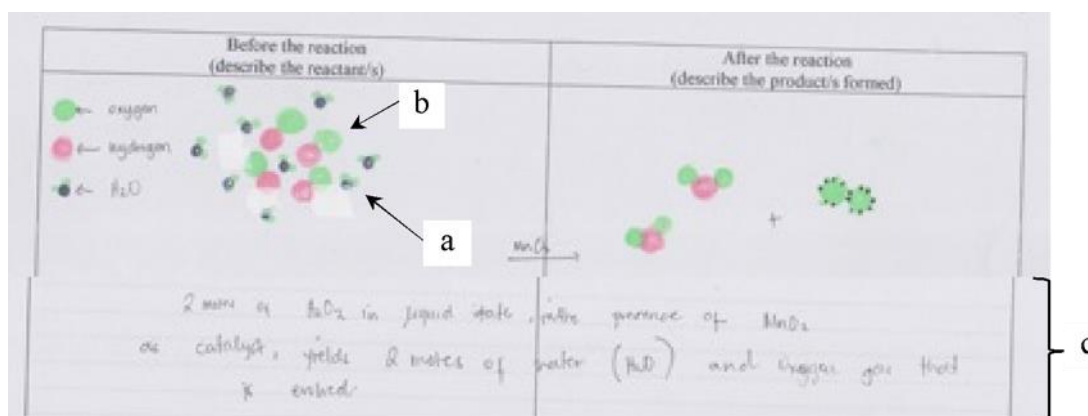
Student 1: I don’t know * that solution. We should be the same. Does it (pointing at hydrogen peroxide, ‘b’) have H_2O (molecules)?

Student 4: Because that is aqueous *. Should we just write it down?

Student 1: Just write it down.

Student 4: I will just write it down.

(Peer-feedback on Student 4)

Figure 94 *Student 4's Drawing*

Nevertheless, the written description of Student 4 (Figure 94) was already about the submicroscopic ideas in the drawing and not on the macroscopic observations (unlike in the teacher-feedback group). Both the teacher and peers recognised, through their feedback, that the written description of the drawing should be complete with details particularly on hydrogen peroxide being an aqueous solution. Teacher-feedback also pointed out that the written description was about the submicroscopic ideas of the decomposition reaction rather than the macroscopic observations. Peers however did not comment that the written description should be about the submicroscopic ideas of the drawing probably because the written description was already about it.

Both assessors often utilised the ‘Identifying an idea’ *move*. Yet the teacher also often utilised the ‘Revising an idea’ as additional feedback *move*. The teacher commented that students should revise their written description because it should be about the submicroscopic ideas rather than the macroscopic observations. In effect, he generated extra feedback episodes than the peers (10 vs. 4). Table 76 presents a summary of the results on the quantitative and qualitative differences between teacher-feedback and peer-feedback *focus* on the ‘written description of the drawing’ for the decomposition reaction.

Table 76 Quantitative and Qualitative Differences Between Teacher-Feedback and Peer-Feedback Focus on the ‘Written Description of the Drawing’ for the Decomposition Reaction

Teacher-feedback	Peer-feedback
<i>Written description of the drawing</i>	
(a) Generated more feedback episodes (10 episodes) than the students’ peers	(a) Generated four feedback episodes
(b) Frequently used ‘Identifying an idea’ and ‘Revising an idea’ as <i>feedback moves</i>	(b) Frequently used ‘Identifying an idea’ as <i>feedback move</i>
(c) Identified that the written description should indicate that the aqueous solution is hydrogen peroxide	(c) Identified that the written description should indicate that hydrogen peroxide is an aqueous solution
(d) Instructed students to revise their written description as it should be about the submicroscopic ideas in the drawing and not on macroscopic observations from the practical work	(d) Did not mention that the written description should be about the submicroscopic ideas in the drawing and not on macroscopic observations from the practical work. This is likely because the written description was already about the submicroscopic ideas.

The results on the qualitative and quantitative analysis of the teacher-feedback and peer-feedback in the ‘verbal linkages with the drawing’ category for the decomposition reaction, the only chemical reaction that did not involve identity transformation, demonstrated the following characteristics of teacher-feedback and peer-feedback:

1. Both teacher-feedback and peer-feedback were focused on the written and not on the oral mode of communicating the ideas in the drawing.
2. Both teacher-feedback and peer-feedback were focused on indicating hydrogen peroxide as an aqueous solution in the written description.
3. Teacher-feedback used the ‘Revising an idea’ *move*. The teacher asked the students to revise their written description about macroscopic observations from the practical work to the submicroscopic ideas in the drawing. Peer-feedback did not use the

‘Revising an idea’ move probably because the written description was already about submicroscopic ideas of the drawing.

The next section presents the quantitative and qualitative analysis of the feedback on the ‘triplet relationship’ category.

10.4 Feedback on the Triplet Relationship

Table 77 presents the frequency of feedback episodes for each *feedback focus* in the teacher-feedback and peer-feedback groups for the decomposition reaction in the ‘triplet relationship’ category.

Table 77 *Frequency of Feedback Episodes for Each Feedback Focus in the Teacher-Feedback and Peer-Feedback Groups in the ‘Triplet Relationship’ Category for the Decomposition Reaction*

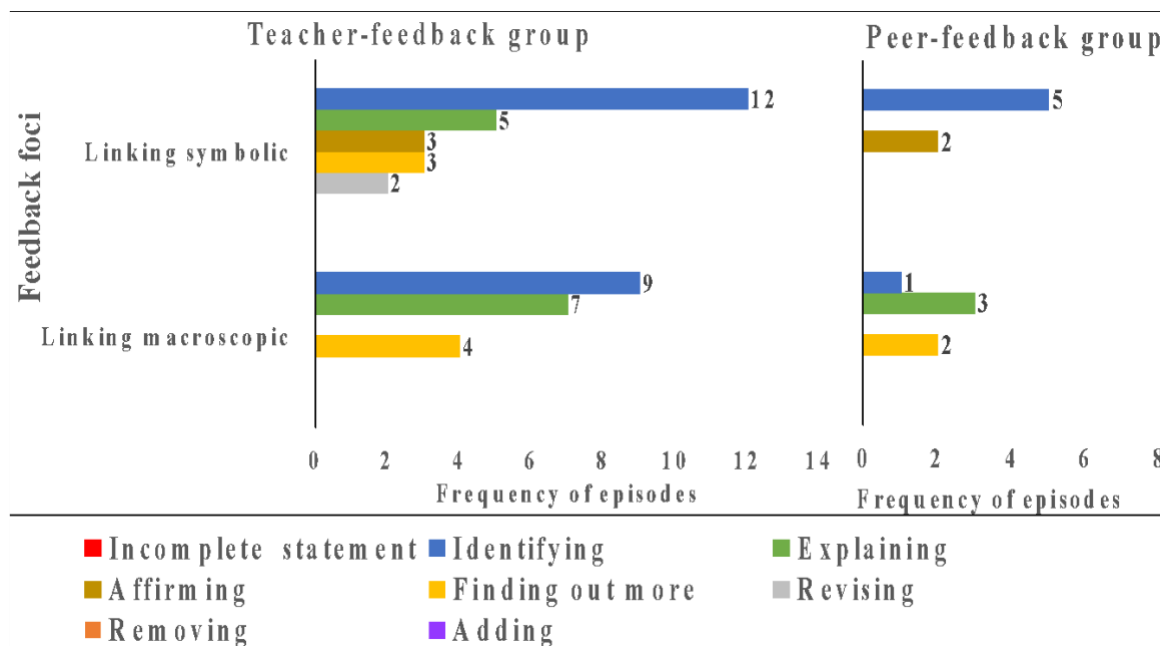
<i>Feedback focus</i>	Teacher-feedback group	Peer-feedback group
Linking symbolic representation (i.e., chemical equation)	25	7
Linking macroscopic observation	20	6
Total	45	13

Table 77 shows that in the ‘triplet relationship’ category, the teacher generated three times more total feedback episodes than the peers (45 vs. 13). The teacher generated roughly one feedback episode in each minute and peers generated one feedback episode in two minutes. If peers were allotted additional 10 minutes to give/receive feedback, they could not generate the same quantity of feedback episodes as the teacher. The greater number of feedback episodes from the teacher may have provided various feedback ideas about the triplet relationship. These feedback ideas were encountered more frequently by teacher-feedback students than peer-feedback students. In effect those feedback ideas may have been reinforced better in the teacher-feedback group than in the peer-feedback group. Examples of

these various feedback ideas were the episodes of teacher-feedback on the drawing of Group 4 (Figure 99) shown in Section 10.4.2. Teacher-feedback was about the linkages among macroscopic observations, submicroscopic ideas in the drawing and prerequisite chemistry knowledge. Such quality of feedback was not exhibited by peer-feedback. Nonetheless, unlike in the combination reaction, here in the decomposition reaction students' peers gave feedback focused on the macroscopic observation.

Table 77 also shows that teacher-feedback group's most frequent *feedback focus* was 'linking symbolic representation (i.e., chemical equation)' and closely followed by the 'linking macroscopic observation'. Figure 95 shows that for both 'linking symbolic representation' and 'linking macroscopic observation', the teacher frequently used 'Identifying an idea' and 'Explaining an idea' as *feedback moves*. In the 'triplet relationship' category, the focus of teacher-feedback was on whether the chemical equation concurred with the submicroscopic ideas in the drawing. Less focus was given on linking the submicroscopic ideas in the drawing to the macroscopic observations from the practical work. The teacher frequently provided explanations to substantiate his feedback ideas about the linkages among the chemical equation, macroscopic observations from the practical work, and submicroscopic ideas in the drawing. Examples of this 'Explaining an idea' *move* are shown in both Sections 10.4.1 (feedback on Group 3's drawing, Figure 96) and 10.4.2 (feedback on Group 4's drawing, Figure 99).

Figure 95 Comparison Between the Teacher-Feedback and Peer-Feedback Moves Used in the ‘Triplet Relationship’ Category for the Decomposition Reaction



In the peer-feedback group, Table 77 shows that the two *feedback foci*: ‘linking symbolic representation (i.e., chemical equation)’ and ‘linking macroscopic observation’ had almost the same frequency of episodes. Figure 95 shows that the ‘linking symbolic representation (i.e., chemical equation)’ was delivered via the ‘Identifying an idea’ and ‘Affirming an idea’ moves. The ‘linking macroscopic observation’ was frequently delivered via the ‘Explaining an idea’ and ‘Finding out more about an idea’ moves. Peer-feedback was equally focused on whether the chemical equation concurred with the submicroscopic ideas in the drawing and the macroscopic observations from the practical work. Additionally, peers did not provide explanations to substantiate their feedback ideas on the chemical equation but provided explanations for feedback focused on the macroscopic observations from the practical work. Examples of these ‘Identifying an idea’ and ‘Explaining an idea’ *feedback moves* are presented in Sections 10.4.1 and 10.4.2.

Both the teacher and students’ peers gave feedback on all three domains of the chemistry triplet: (1) macroscopic domain – observations from the practical work on the

decomposition of hydrogen peroxide; (2) submicroscopic domain – the visual-spatial elements of the drawing; and the (3) symbolic domain – the chemical equation of the chemical reaction. For feedback focused on ‘linking symbolic representation’, i.e., whether the chemical equation concurred with the submicroscopic ideas in the drawing, the teacher provided explanations while peers did not. These explanations may have reinforced the feedback ideas better for the teacher-feedback students. For feedback focused on ‘linking macroscopic observation’, i.e., whether the submicroscopic ideas in the drawing were linked with the macroscopic observations from the practical work, both the teacher and peers provided explanations that may have reinforced the feedback ideas for both feedback groups. Table 87 presents a summary of the results on the general quantitative and qualitative differences between teacher-feedback and peer-feedback in the ‘triplet relationship’ category for the decomposition reaction.

Table 78 General Quantitative and Qualitative Differences Between Teacher-Feedback and Peer-Feedback in the ‘Triplet Relationship’ Category for the Decomposition Reaction

Teacher-feedback	Peer-feedback
<i>Triplet relationship</i>	
(a) Generated more total feedback episodes (45 episodes) than the students’ peers	(a) Generated 13 feedback episodes
(b) <i>Feedback foci</i> concentrated on linking the submicroscopic ideas in the drawing to the chemical equation and macroscopic observations from the practical work	(b) <i>Feedback foci</i> concentrated on linking the submicroscopic ideas in the drawing to the chemical equation. There was also feedback on the macroscopic observations from the practical work
(c) Frequently utilised ‘Identifying an idea’ and ‘Explaining an idea’ as <i>feedback moves</i> for the two <i>feedback foci</i>	(c) For <i>feedback focus</i> on ‘linking symbolic representation’, the students frequently utilised ‘Identifying an idea’ and ‘Affirming an idea’ as <i>feedback moves</i> . For <i>feedback focus</i> on ‘linking macroscopic observation’, ‘Identifying an idea’ and ‘Explaining an idea’ <i>moves</i> were frequently utilised.

The next sections discuss further how the quality of feedback differs for the teacher-feedback and peer-feedback groups in the two *feedback foci* in the ‘triplet relationship’ category: (1) linking symbolic representation (i.e., chemical equation), and (2) linking macroscopic observation.

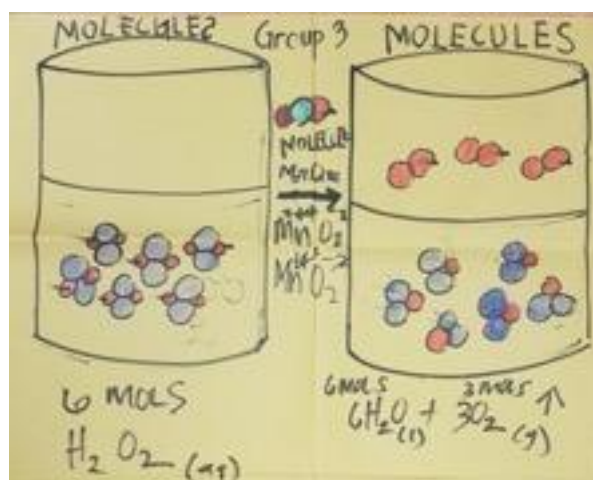
10.4.1 Linking Symbolic Representation (i.e., Chemical Equation)

For feedback focused on ‘linking symbolic representation’, teacher-feedback explained that the ratio between the number of molecules of each chemical species in the drawing should reflect the ratio of the coefficients in the balanced chemical equation: $2\text{H}_2\text{O}_{2(\text{aq})} \rightarrow 2\text{H}_2\text{O}_{(\text{l})} + \text{O}_{2(\text{g})}$. In the following teacher’s feedback on the drawing of Group 3 (Figure 96), the teacher pointed out that the ratio between the number of molecules of each chemical species in the drawing was 6:6:3. And that this ratio was still the same as 2:2:1, which were the number of moles of each chemical species in the balanced chemical equation.

The ratio remains the same. 6 6 2 remains, oh 6 6 3 remains, 2 2 1. That's why the balanced chemical equation for the decomposition of hydrogen peroxide is two moles of H_2O_2 will form two moles of water and one mole of oxygen.

(Teacher-feedback on Group 3)

Figure 96 Group 3's Drawing



Additionally in the following exchanges between the teacher and Student 5 of Group 8 while looking at the group's drawing (Figure 97), the teacher pointed out that the coefficient of oxygen in the balanced chemical equation (see 'a'), which was one (1) did not match the number of oxygen molecules in the drawing, which was two (2) (see 'b').

Teacher: How many molecules of oxygen in your product? In your illustration (pointing at 'b')?

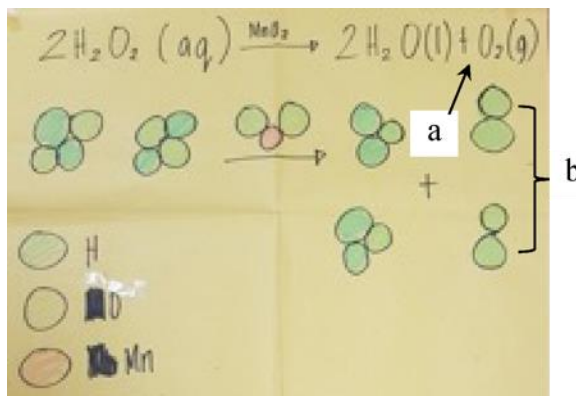
Student 5: Two.

Teacher: Two. So, do you have two in your balanced equation? Do you have two in your balanced equation? Just one (pointing at 'a'), right?

Student 5: Oh, yes.

(Teacher-feedback on Group 8)

Figure 97 Group 8's Drawing



Meanwhile peers were focused on identifying how to correctly draw: (a) the molecules of the chemical species based on the chemical formulae in the chemical equation, $2\text{H}_2\text{O}_{2(\text{aq})} \rightarrow 2\text{H}_2\text{O}(\text{l}) + \text{O}_{2(\text{g})}$, and (b) the number of molecules of the chemical species based on the coefficients in the balanced chemical equation, 2:2:1. In the following exchanges between peers while looking at the drawing of Student 5 (Figure 98), the chemical formula of hydrogen peroxide is H_2O_2 and Student 5 drew the molecule as two oxygen and two hydrogen atoms bonded together. Also, since two was the coefficient of hydrogen peroxide in the chemical equation, Student 5 drew two molecules of it.

Student 5: Since it is $2\text{H}_2\text{O}_2$, what I did was, first it is H_2O_2 , so I drew two oxygen (atoms) and two hydrogen (atoms) together. Then, since its $2\text{H}_2\text{O}_2$, two separate H_2O_2 (molecules). Is that correct?

Student 4: Yes.

Student 5: And then two oxygen (atoms) together and then I indicated gas.

Student 1: There could be many molecules in the sketch, and it should still be equal to the ratio (i.e., 2, 2,1). Also, we should sketch them (molecules) based on the chemical formulae in the equation.

(Peer-feedback on Student 5)

Figure 98 *Student 5's Drawing*



Teacher-feedback on ‘linking symbolic representation’ (i.e., whether the chemical equation concurred with the submicroscopic ideas in the drawing) was solely focused on whether the quantitative relationship of the chemical species in the drawing matched the quantitative relationship in the chemical equation. Peer-feedback was rather focused on two things: (a) whether the drawing of the molecules matched with the chemical formulae in the chemical equation and (b) whether the number of molecules in the drawing matched with the coefficient in the chemical equation. Consequently, both teacher-feedback and peer-feedback students accurately drew the molecules of the chemical species based on the chemical formulae, albeit students’ peers were explicit in pointing this out in their feedback.

Additionally, the teacher provided explanations to substantiate the identified feedback ideas whereas peers (Students 4 and 1) did not provide an explanation to their feedback on the drawing of Student 5. Explanation was not provided probably because Student 5 accurately explained how he/she linked the identity and number of molecules in the drawing with the chemical equation. Quantitatively the teacher generated roughly three times more feedback episodes than the peers (25 vs. 7) (see Table 77). Such a greater number of feedback

episodes may have caused teacher-feedback students to encounter those feedback ideas more frequently than the peer-feedback students. Table 79 presents a summary of the results on the quantitative and qualitative differences between teacher-feedback and peer-feedback focused on ‘linking symbolic representation (i.e., chemical equation)’ for the decomposition reaction.

Table 79 *Quantitative and Qualitative Differences Between Teacher-Feedback and Peer-Feedback Focus on ‘Linking Symbolic Representation (i.e., Chemical Equation)’ for the Decomposition Reaction*

Teacher-feedback	Peer-feedback
<i>Linking symbolic representation (i.e., chemical equation)</i>	
(a) Generated more feedback episodes (25 episodes) than the students’ peers	(a) Generated seven feedback episodes
(b) Often utilised ‘Identifying an idea’ and ‘Explaining an idea’ as <i>feedback moves</i>	(b) Utilised ‘Identifying an idea’ and ‘Affirming an idea’ as <i>feedback moves</i>
(c) Feedback focused on matching the quantitative relationship between the chemical species in the drawing and the balanced chemical equation	(c) Feedback focused on: (1) coefficients in the balanced chemical equation were correctly represented in the drawing; and (2) chemical formulae in the equation matched the drawing of the molecules of chemical species

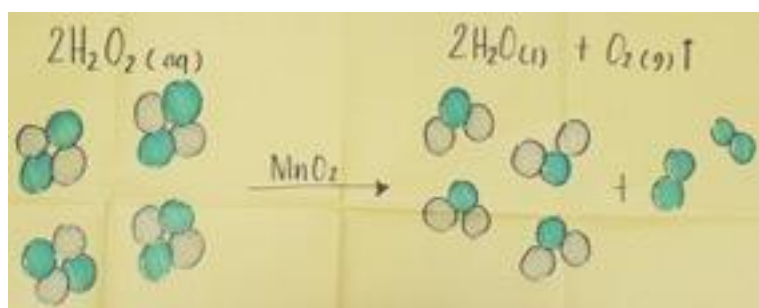
10.4.2 Linking Macroscopic Observation

For feedback focused on ‘linking with macroscopic observation’, the teacher made a linkage between the submicroscopic ideas in the drawing and the macroscopic observations from the practical work. Teacher-feedback explained the connection: (a) among the identity of the product, its chemical property, and students’ macroscopic observation, and (b) between distance among particles and the physical property of the substance. In the first quote of the teacher’s feedback on the drawing of Group 4 (Figure 99), the teacher pointed out that oxygen was a product of the chemical reaction as demonstrated by the glowing wooden

splint. In the second quote of the teacher's feedback on the same drawing (Figure 99), the teacher linked the spaces between liquid molecules and the ability of liquids to flow.

So, the glowing splint placed over the beaker containing the mixture of hydrogen peroxide and manganese dioxide produces oxygen. And that oxygen will, as you know, support burning or combustion. That is why you observed that the glowing splint burst into flame.
(Teacher-feedback on Group 4)

Figure 99 *Group 4's Drawing*



The molecules of the liquid are quite touching, which allow them to slide past one another. That is why water can flow, because of the little spaces between them (molecules).
(Teacher-feedback on Group 4)

Furthermore teacher-feedback linked macroscopic observation and prerequisite chemistry knowledge. In the following quote of the teacher's feedback on the same drawing of Group 4 (Figure 99), the teacher explained that catalyst was not consumed in the chemical reaction. The teacher then used students' macroscopic observation to support this explanation.

What is the role of the catalyst? The catalyst speeds up the reaction without being consumed in the reaction. That is why after the reaction you observed that the manganese dioxide or the manganese oxide was still there. It was not affected by the change.

(Teacher-feedback on Group 4)

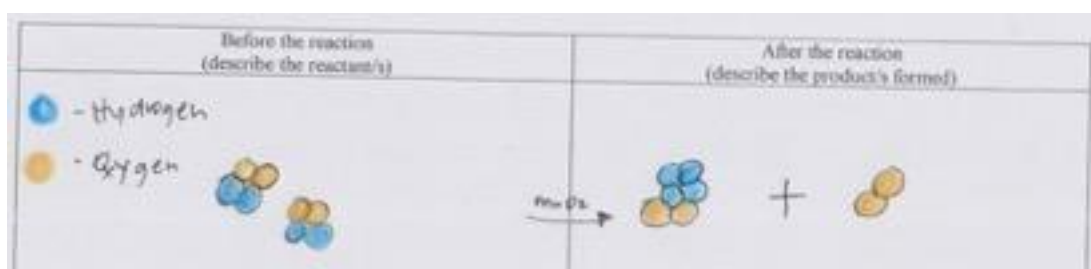
A peer gave feedback on the macroscopic observation from the practical work, yet he/she did not link it with the submicroscopic ideas in the drawing nor to any prerequisite chemistry knowledge. In the following peer-feedback on the drawing of Student 3 (Figure 100), the peer described what he/she observed from the practical work on the glowing wooden splint without relating it to the drawing.

What happened was when we lit the wooden splint, it started to burn because of the ... Then there is the question, what happened to the wooden splint? So, the wooden splint burned and produced smoke because of *. It is because of the flame that the wooden splint was able to produce smoke. Here in question number 4, what is being asked is about the wooden splint.

(Peer-feedback on Student 3)

*Incomprehensible

Figure 100 *Student 3's Drawing*



In the foregoing peer-feedback on the drawing of Student 3 (Figure 100), the peer attempted to mention what caused the wooden splint to burn. However, he/she discontinued his/her thoughts about it. The peer either did not know or was uncertain about whether oxygen gas made the wooden splint burned.

Quantitatively the teacher generated roughly three times more feedback episodes than the peers (20 vs. 6) (see Table 77) for the feedback focused on ‘linking macroscopic observation’. This greater number of teacher-feedback episodes may be brought about by the various feedback ideas on the linkages among the macroscopic observations from the practical work, visual-spatial elements of the drawing and prerequisite chemistry knowledge. Meanwhile peer-feedback was focused on the macroscopic observation per se, without linkage with the visual-spatial details of the drawing nor with prerequisite chemistry knowledge. Nevertheless, both teacher-feedback and peer-feedback frequently provided explanations to substantiate their feedback ideas. Table 80 presents a summary of the results on the quantitative and qualitative differences between teacher-feedback and peer-feedback focused on ‘linking macroscopic observation’ for the decomposition reaction.

Table 80 *Quantitative and Qualitative Differences Between Teacher-Feedback and Peer-Feedback Focus on ‘Linking Macroscopic Observation’ for the Decomposition Reaction*

Teacher-feedback	Peer-feedback
<i>Linking macroscopic observation</i>	
(a) Generated more feedback episodes (20 episodes) than the students’ peers	(a) Generated six feedback episodes
(b) Often used ‘Identifying an idea’ and ‘Explaining an idea’ as <i>feedback moves</i>	(b) Often used ‘Explaining an idea’ and ‘Finding out more about an idea’ as <i>feedback moves</i>
(c) Feedback was focused on linking the submicroscopic ideas in the drawing, prerequisite chemistry knowledge, and macroscopic observations from practical work	(c) Feedback was focused on macroscopic observation without linking it to the submicroscopic ideas in the drawing nor to prerequisite chemistry knowledge

The results on the qualitative and quantitative analysis of the teacher-feedback and peer-feedback focused on the ‘triplet relationship’ category for the decomposition reaction, the only chemical reaction that did not involve identity transformation demonstrated the following characteristics of teacher-feedback and peer-feedback:

1. Both teacher-feedback and peer-feedback linked the submicroscopic ideas in the drawing and the chemical equation.
2. Teacher-feedback linked the students’ macroscopic observations from the practical work, the visual-spatial elements of the drawing, and prerequisite chemistry knowledge. Peer-feedback did not make such linkages. Peer-feedback described a macroscopic observation but did not link it with the other domains of the chemistry triplet nor to other *feedback foci*.
3. Teacher-feedback generated a greater number of feedback episodes than peer-feedback. Consequently teacher-feedback students encountered more feedback ideas.

These more feedback ideas may have reinforced the understanding of the triplet relationship better for the teacher-feedback students.

4. Teacher-feedback consistently provided explanations to substantiate feedback ideas for the linkages among the three domains of the chemistry triplet. Peer-feedback provided explanations on the macroscopic domain but did not relate it to the submicroscopic nor symbolic domains of the triplet relationship.

The following section presents the quantitative and qualitative analysis of the feedback on the ‘prerequisite chemistry knowledge’ and ‘cannot identify content’ categories.

10.5 Feedback on Prerequisite Chemistry Knowledge and Cannot Identify Content

Table 81 presents the frequency of feedback episodes in the teacher-feedback and peer-feedback groups for the decomposition reaction in the feedback on ‘prerequisite chemistry knowledge’ and ‘cannot identify content’ categories.

Table 81 *Frequency of Feedback Episodes in the Teacher-Feedback and Peer-Feedback Groups in the ‘Prerequisite Chemistry Knowledge’ and ‘Cannot Identify Content’ Categories for the Decomposition Reaction*

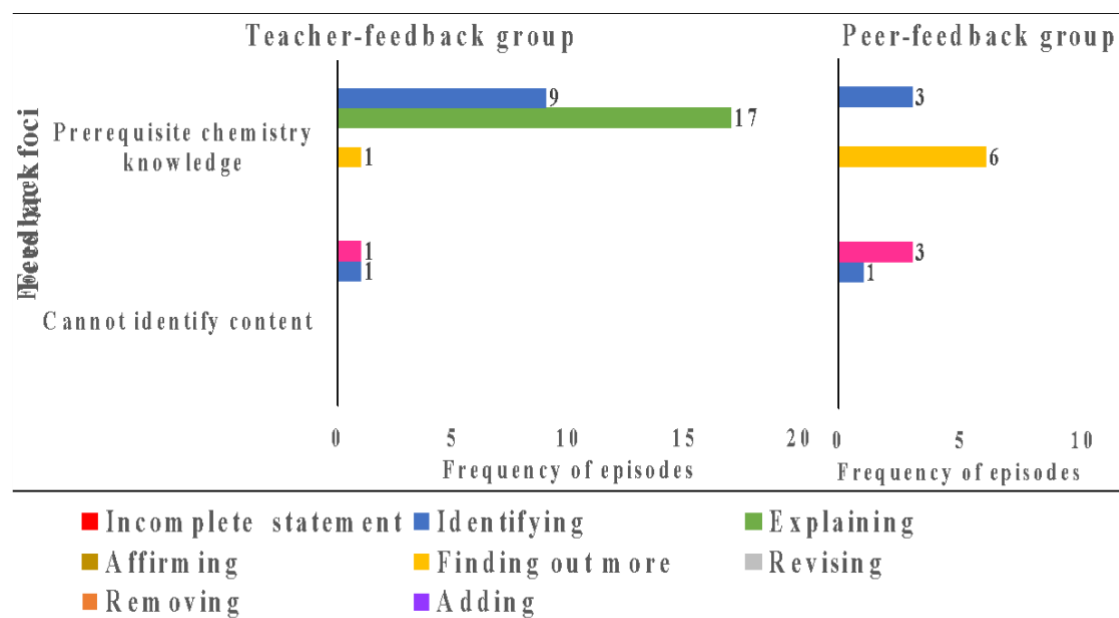
Feedback category	Teacher-feedback group	Peer-feedback group
Prerequisite chemistry knowledge	27	9
Cannot identify content	2	4

Table 81 shows that the teacher generated three times more feedback episodes than the peers (27 vs. 9) in the ‘prerequisite chemistry knowledge’ category. Peers generated two times more feedback episodes than the teacher (2 vs. 4) in the ‘cannot identify content’ category. In the ‘prerequisite chemistry knowledge’ category, the teacher generated six to seven feedback episodes in 10 minutes while peers generated three feedback episodes in 10 minutes. If peers were given additional 10 minutes for their total time to give/receive

feedback, they still could not generate the same number of teacher-feedback episodes. The teacher gave more feedback ideas on chemistry concepts that students learned from their previous chemistry lessons. Such previously learned chemistry concepts were linked to the other feedback categories especially to the ‘visual-spatial elements in the drawing’ category. Peers gave less feedback ideas on previously learned chemistry concepts. Examples of these previously learned chemistry concepts and the associated ideas from the other feedback categories are presented in Section 10.5.1 for both teacher-feedback and peer-feedback groups. The greater number of feedback ideas from the teacher may have caused teacher-feedback students to be cognitively engaged with more chemistry concepts than the peer-feedback students. Doing so may have reinforced the understanding of more chemistry concepts and the associated ideas from the other feedback categories. In the ‘cannot identify content’ category, the peers generated two times more incomprehensible feedback episodes than the teacher (4 vs. 2); even though they had a shorter time than the teacher to give feedback (30 vs. 40 minutes). Most of the time, teacher-feedback carried complete and intelligible thoughts compared to peer-feedback.

For *feedback moves*, Figure 101 shows that for the ‘prerequisite chemistry knowledge’ category, the teacher often used ‘Explaining an idea’ and ‘Identifying an idea’. In giving feedback about previously learned chemistry concepts, the teacher often provided explanations to substantiate the feedback ideas. Examples of this ‘Explaining an idea’ *move* are teacher’s feedback on the drawings of Group 4 (Figure 102) and 3 (Figure 103) in Section 10.5.1. In the ‘cannot identify content’ category the teacher had two feedback episodes. One feedback episode was delivered via ‘Identifying an idea’ and the other was an ‘incomplete feedback statement’. The teacher generated two feedback episodes that were unintelligible for the researcher. One was an incomplete feedback statement while the other one appeared to be identifying an idea. These two *feedback moves* are shown in Section 10.5.2.

Figure 101 Comparison Between the Teacher-Feedback and Peer-Feedback Moves Used in the ‘Prerequisite Chemistry Knowledge’ and ‘Cannot Identify Content’ Categories for the Decomposition Reaction



In the peer-feedback group, Figure 101 shows that in the ‘prerequisite chemistry knowledge’ category, students used ‘Finding out more about an idea’ and ‘Identifying an idea’ moves. Peers posed questions that sought further information and identified feedback ideas about chemistry concepts that they previously learned. An example of this ‘Finding out more about an idea’ move is the only peer-feedback on the drawing of Student 4 (Figure 105) shown in Section 10.5.1. In the ‘cannot identify content’ category peers frequently generated ‘incomplete feedback statements’. The peers gave incomplete feedback statements, where the content cannot be comprehended by the researcher.

The teacher provided greater quantity of feedback ideas about chemistry concepts that students had learned from their previous chemistry lessons. These feedback ideas were substantiated by explanations. Whereas peers often posed questions to deliver feedback about previously learned chemistry concepts. More so teacher-feedback was more likely than peer-feedback to give feedback statements that were complete and intelligible for the researcher.

The explanations and comprehensible feedback messages from the teacher may have cultivated a better understanding of the prerequisite chemistry concepts and the associated ideas from the other feedback categories. Table 82 presents a summary of the results on the general quantitative and qualitative differences between teacher-feedback and peer-feedback in the ‘prerequisite chemistry knowledge’ and ‘cannot identify content’ categories for the decomposition reaction.

Table 82 *General Quantitative and Qualitative Differences Between Teacher-Feedback and Peer-Feedback in the ‘Prerequisite Chemistry Knowledge’ and ‘Cannot Identify Content’ Categories for the Decomposition Reaction*

Teacher-feedback	Peer-feedback
<i>Prerequisite chemistry knowledge</i>	
(a) Generated three times more feedback episodes (27 episodes) than the students’ peers	(a) Generated nine feedback episodes
(b) Frequently used ‘Explaining an idea’ and ‘Identifying an idea’ as <i>feedback moves</i>	(b) Used ‘Finding out more about an idea’ and ‘Identifying an idea’ as <i>feedback moves</i>
<i>Cannot identify content</i>	
(a) Generated two feedback episodes	(a) Generated twice more feedback episodes (four episodes) than the teacher
(b) Used ‘Identifying an idea’ as a <i>feedback move</i> . Additionally, one episode was an ‘Incomplete feedback statement’	(b) Most feedback episodes were ‘Incomplete feedback statements’

10.5.1 Prerequisite Chemistry Knowledge

The greater number of teacher-feedback episodes on the ‘prerequisite chemistry knowledge’ category was about previously learned chemistry concepts related to the other feedback categories, i.e., visual-spatial elements of the drawing, verbal linkages with the drawing, and triplet relationship. For example, there was feedback on the concept of covalent

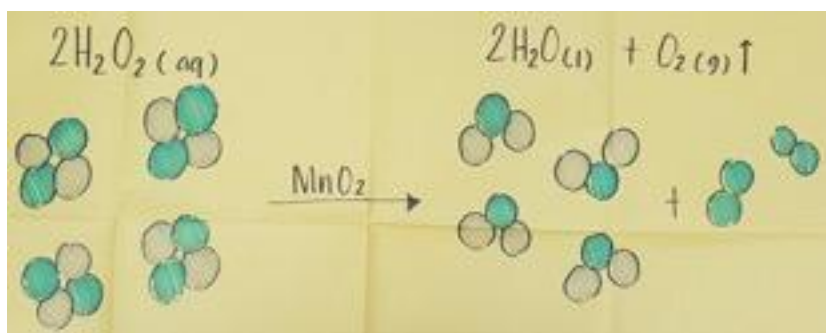
bonding and how it was related to the identity of the chemical species. There was also feedback on properties of ionic compounds and how it linked to the distance between particles. And there was feedback on the presence of a catalyst and how it was associated with the students' macroscopic observations during the practical work. Such feedback on previously learned chemistry concepts served as explanations of the ideas from the other feedback categories. These previously learned chemistry concepts are listed below. Quotes or exchanges of sample feedback episodes and sample drawings are shown for each concept:

(a) Catalyst and its role during a chemical reaction

What was the role of the catalyst? The catalyst sped up the reaction without being consumed in the reaction. That is why after the reaction you observed that the manganese dioxide or the manganese (IV) oxide was still there. It was not affected by the change. Its presence only hastened or sped up the reaction. That is why manganese dioxide is not part of the product.

(Teacher-feedback on Group 4)

Figure 102 *Group 4's Drawing*



This teacher-feedback on the drawing of Group 4 (Figure 102) about the role of a catalyst during the chemical reaction was useful in explaining students' macroscopic

observation during the practical work, i.e., why manganese dioxide or manganese (IV) oxide remained unchanged in the solution after the chemical reaction. Also, this feedback on the concept of a catalyst was useful to support understanding of why the products of the decomposition reaction were only liquid water and oxygen gas but not manganese nor its compounds.

(b) Chemical property of a substance

So, the glowing splint placed over the beaker containing the mixture of hydrogen peroxide and manganese dioxide produced oxygen. And that oxygen will as you know supported burning or combustion. That is why you observed that the glowing splint burst into flame. Because it (oxygen) supported burning or combustion.

(Teacher-feedback on Group 4)

On the same drawing of Group 4 (Figure 102), this teacher-feedback describing the chemical property of oxygen as flammable was useful in explaining the students' macroscopic observation of why the wooden splint burned.

(c) Exothermic reaction

Teacher: Okay you mentioned of the changes that happened. You mentioned 'exothermic'. If you can feel, if you can feel the beaker, its temperature. Did you use the thermometer? How did you know that there was a temperature change?

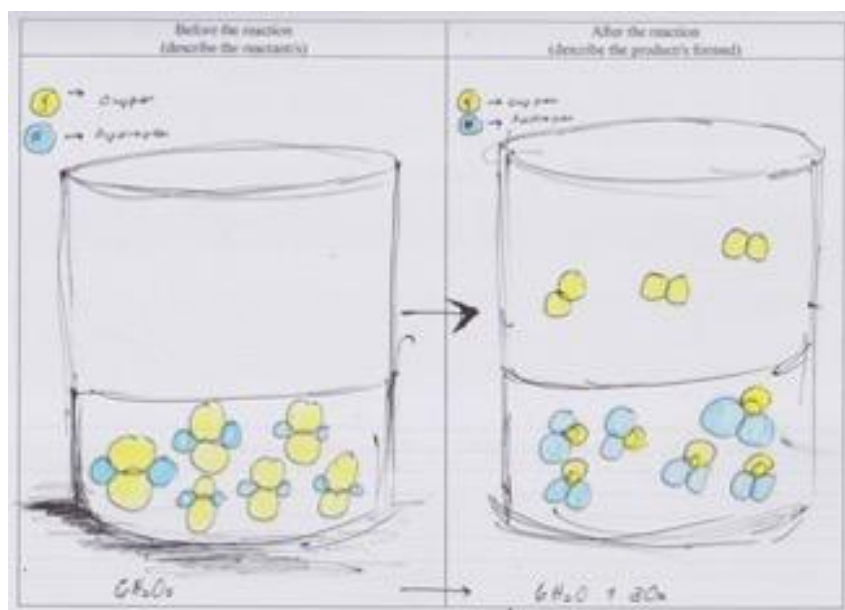
Student 4: We touched it.

Teacher: Okay so you touched the wall of the beaker. And then there was a slight increase in temperature. That indicated that the hydrogen peroxide was in contact with manganese

dioxide and releases energy, in the form of heat energy. That made the beaker's wall a bit warm.

(Teacher-feedback on Group 3)

Figure 103 *Group 3's Drawing*

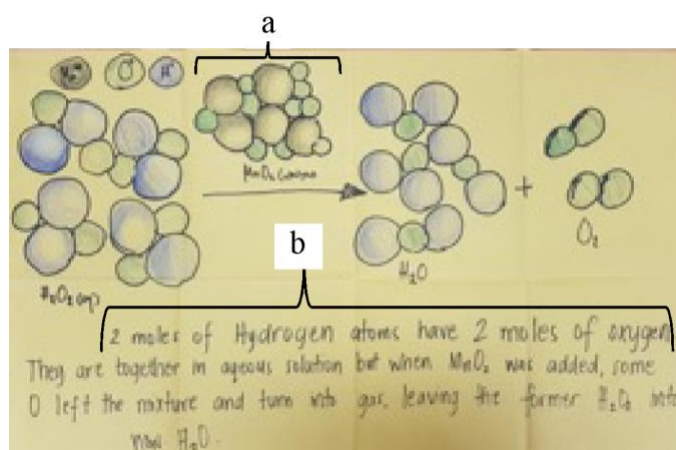


This teacher-feedback on the drawing of Group 3 (Figure 103) about the concept of exothermic reaction was useful in explaining students' macroscopic observation of why the beaker containing the decomposition reaction felt warm. Additionally, this teacher-feedback on exothermic reaction was related to another chemistry concept, which was the production of heat as evidence of a chemical reaction.

(d) Nature of the compound

It is nice that you have the catalyst there (pointing at 'a') as arranged because manganese dioxide is a bit ionic. That is why all the atoms are closely packed together.

(Teacher-feedback on Group 2)

Figure 104 Group 2's Drawing

This teacher-feedback on the drawing of Group 2 (Figure 104), which pointed out that manganese dioxide/manganese (IV) oxide is an ionic solid was related to drawing distance between particles of solid as tightly packed.

(e) Covalent bonding

Kindly revise that one (pointing at 'b' in Figure 104): *two moles of hydrogen atoms and two moles of oxygen*. Instead of having that one, you just say: *two moles of hydrogen peroxide or H_2O_2* . So that makes sense. Because they are together now. Because they are covalently bonded, so therefore, you can say: *two moles of hydrogen peroxide*.

(Teacher-feedback on Group 2)

In the written description for the drawing of Group 2 (Figure 104), teacher-feedback mentioned covalent bonding and how it was related to the identity of the reactant as hydrogen peroxide molecule and not as 'two moles of hydrogen atoms and two moles of oxygen'. Peer-feedback on prerequisite chemistry knowledge was focused on a single chemistry concept, i.e., catalyst's role. Peers posed questions that sought further information on what a catalyst

does. This ‘Finding out more about an idea’ *feedback move* is illustrated in the following exchanges on the drawing of Student 4 (Figure 105):

Student 1: Then, what do we do for the catalyst here? What is the correct thing to do?

Student 5: I do not know. As for me, I just wrote it.

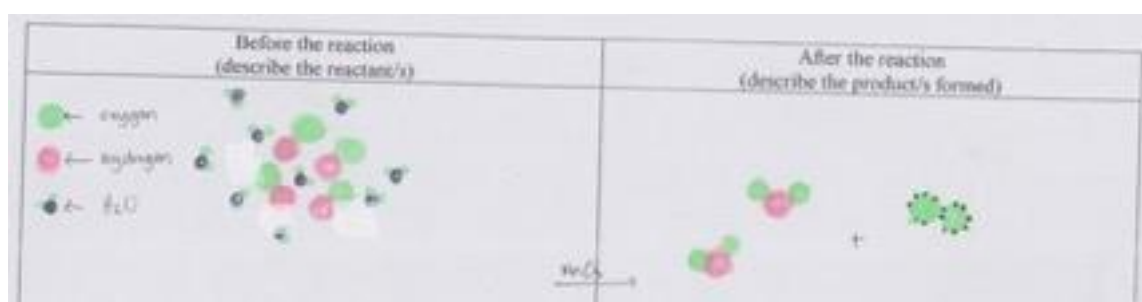
Student 1: I do not know. What is the meaning of a catalyst?

Student 5: Speeds up a chemical reaction.

Student 1: Yes, that’s just it, but I do not know what happened at the subatomic level.

(Peer-feedback on Student 4)

Figure 105 *Student 4’s Drawing*



Peers knew the ‘book definition’ of a catalyst. Student 1 posed a question to know what happened to the catalyst at the submicroscopic level. This was probably to help Student 1 in drawing the catalyst. However, asking the question was not productive for the peers. In the exchanges asking the question did not yield further description of the catalyst apart from the ‘book definition’. More so unlike the teacher, peers did not relate the concept about the catalyst to the feedback ideas from the other feedback categories.

10.5.2 Cannot Identify Content

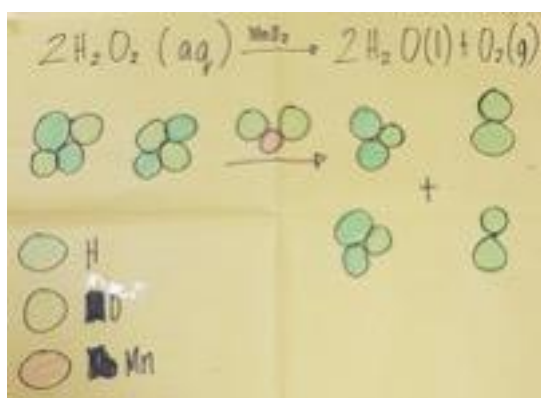
The teacher had two feedback episodes where content cannot be identified. One was an incomplete feedback statement (teacher-feedback on Group 8’s drawing, Figure 106) and

the second appeared to be identifying something about the water molecules (teacher-feedback on Group 4's drawing, Figure 107). In both feedback episodes, the researcher was not certain what the teacher meant.

If you add more molecules of H_2O_2 ...

(Teacher-feedback on Group 8)

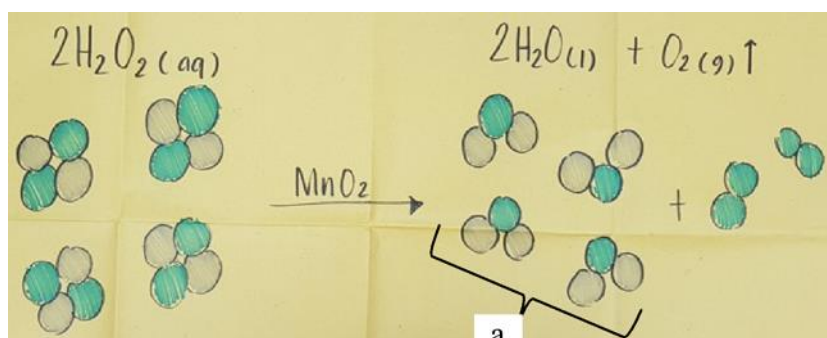
Figure 106 Group 8's Drawing



Okay, of course, water has that one (pointing at 'a').

(Teacher-feedback on Group 4)

Figure 107 Group 4's Drawing

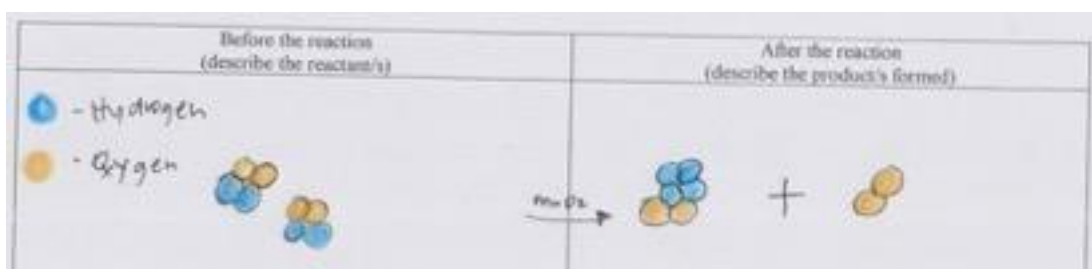


Peers had more feedback episodes than the teacher where the content cannot be identified. Most of these feedback episodes were incomplete feedback statements. Examples are peer-feedback on Students 3 (Figure 108) and 4's (Figure 109) drawings. Peers were more likely than the teacher to give incomplete feedback episodes.

The atoms are...

(Peer-feedback on Student 3)

Figure 108 *Student 3's Drawing*

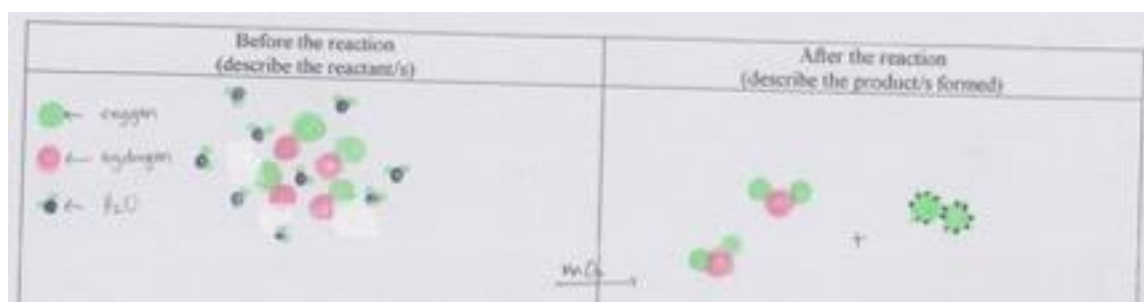


And then actually the...

And the MnO is...

(Peer-feedback on Student 4)

Figure 109 *Student 4's Drawing*



The results on the qualitative and quantitative analysis of the teacher-feedback and peer-feedback in the ‘prerequisite chemistry knowledge’ and ‘cannot identify content’ categories for the decomposition reaction, the only chemical reaction that did not involve identity transformation, demonstrated the following characteristics of teacher-feedback and peer-feedback:

1. Teacher-feedback identified and explained (*feedback moves*) several previously learned chemistry concepts and then related it to other *feedback foci*. Such previously learned chemistry concepts include catalyst and its role during a chemical reaction, chemical property of a substance, exothermic reaction, nature of the compound, and covalent bonding. These previously learned chemistry concepts may have substantiated the understanding of the other *feedback foci*, i.e., linking macroscopic observations, distance between particles, identity of chemical species, written description of the drawing, and another previously learned chemistry concept (i.e., evidence of chemical reaction). Whereas peer-feedback commented on a single chemistry concept, i.e., the role of a catalyst. Peers did not relate the feedback on the role of a catalyst to other *feedback foci*.
2. Teacher-feedback was more likely than peer-feedback to provide complete feedback statements.

Chapter 11 Features of Feedback that are Valuable in Supporting Drawing to Learn Chemical Reactions

This chapter discusses the feedback features valuable in supporting drawing to learn the different reaction types. These feedback features are synthesised from the two feedback sources. The chapter begins with a summary of the notable findings from the comparison of the two feedback sources in Chapters 9 and 10. Then features of feedback valuable in supporting drawing to learn reactions in large classes are presented.

11.1 Features of Teacher-Feedback and Peer-Feedback

This section presents the summary of the comparison of the features of the two feedback sources across the two chemical reactions – one involved transformation from atoms and molecules to ions (combination) while the other involved molecules remaining as molecules (decomposition). These features include number of feedback episodes, *feedback foci* and *feedback moves*. Table 83 presents these features of the two feedback sources.

Table 83 Comparison Between the Features of Teacher-Feedback and Peer-Feedback on Drawing Combination and Decomposition Reactions

Chemical reaction	Features	Teacher-feedback (<i>active learning</i>)	Peer-feedback (<i>interactive learning</i>)
	Number	• More episodes across all four feedback categories	• Less episodes across all four feedback categories
Transformation from atoms and molecules to ions	<i>Foci</i>	• Visual elements: ○ Transformation of reactants to product (atoms and molecules to ions)	• Visual elements: ○ Identity of the reactants only; no transformation
<i>Combustion of solid magnesium</i>		○ Application of the Law of Mass Conservation	○ Uncertain on how to apply the Law of Mass Conservation
$2\text{Mg}_{(s)} + \text{O}_{2(g)} \rightarrow 2\text{MgO}_{(s)}$		• Spatial elements: ○ Particle arrangement of both reactant (Mg, a metallic solid) and product (MgO, an ionic solid)	• Spatial elements: ○ Particle arrangement of one reactant (Mg)

		○ Distinction between distances of solid and gaseous particles ○ Add more particles to show the correct phases ● Linkages among visual-spatial elements, chemical equation, and macroscopic observations ● Variety of prerequisite chemistry concepts that substantiated other <i>feedback foci</i>	○ Distinction between distances of particles of solid and gas ○ Add more particles to show the correct phases ● Linkages only on the chemical equation (No linkages with the visual-spatial elements and macroscopic observations) ● Only one prerequisite chemistry concept (i.e., mole) and was not linked to other <i>feedback foci</i>
	Moves	● Complete statements and often supported with explanations	● Incomplete statements and often asked questions
	Number	● More episodes across all four feedback categories	● Less episodes across all four feedback categories
Molecules remained as molecules		● Visual elements: ○ Students readily know that ‘atoms’ and ‘molecules’ were the accurate particle identities. But the teacher explicitly identified such particles bear no charges ○ Application of the Law of Mass Conservation	● Visual elements: ○ Students readily know that ‘atoms’ and ‘molecules’ were the accurate particle identities. No mentioning of charges ○ Application of the Law of Mass Conservation
Decomposition of aqueous hydrogen peroxide $2\text{H}_2\text{O}_{2(\text{aq})} \rightarrow 2\text{H}_2\text{O}_{(\text{l})} + \text{O}_{2(\text{g})}$	Foci	● Spatial elements: ○ Scattered arrangement of liquid particles ○ Draw water molecules surrounding solute particles in aqueous solution ○ More molecules of the liquid species to show its dispersion ○ Accurate distinction between the distances of liquid and gaseous particles ● Linkages among visual-spatial elements, chemical	● Spatial elements: ○ Scattered arrangement of liquid particles ○ Draw water molecules surrounding solute particles in aqueous solution ○ No feedback on the number of liquid molecules ○ Incorrectly described distance among liquid particles as wide

	equation, and macroscopic observations	• Linkage between visual-spatial elements and chemical equation but not with macroscopic observations
	• Variety of prerequisite chemistry concepts that substantiated other <i>feedback foci</i>	• Only one prerequisite chemistry concept (i.e., catalyst's role in chemical reaction) and was not linked to other <i>feedback foci</i>
Moves	• Often complete statements supported with explanations • Used questions productively	• Had more incomplete statements • Often asked questions productively

The following were consistent observations from the two feedback groups in both reactions as shown in Table 83:

- (1) Teacher-feedback generated more feedback ideas than peer-feedback.
- (2) Teacher-feedback focused on substantiating feedback ideas with more prerequisite chemistry concepts than peer-feedback.
- (3) Teacher-feedback gave intelligible feedback more often than peer-feedback.
- (4) Teacher-feedback *move* was often explaining feedback ideas whereas peer-feedback was often posing questions.

The following were notable observations that vary depending on whether the chemical reaction involved (combination) or did not involve transformation (decomposition) from atoms and molecules to ions as also shown in Table 83:

- (1) For the combination reaction: teacher-feedback focused on the visual and spatial elements of both reactant and product, e.g., identity and arrangement of Mg and MgO. Consequently teacher-feedback recognized transformation from atoms and/or

molecules to ions. Peer-feedback focused on the visual and spatial elements of a reactant, e.g., identity and arrangement of Mg.

- (2) For the decomposition reaction, teacher-feedback identified particles involved in the reaction bear no charges albeit both feedback groups readily identified *atoms* and *molecules* as the accurate particle identities.
- (3) Only teacher-feedback accurately described conservation of particles for combination reaction whereas both feedback sources accurately described conservation of particles for the decomposition reaction.
- (4) Teacher-feedback distinguished between distances of particles within liquid and gas while both feedback sources distinguished between distances of solid and gaseous particles.
- (5) Teacher-feedback suggested adding more liquid particles to accurately show its phase whereas both feedback sources suggested to add more solid and gaseous particles to accurately show their phases.
- (6) Both feedback sources recognized the particle arrangement of liquid as scattered.
- (7) Both feedback sources suggested to add more water molecules surrounding solute particles in drawing aqueous solution.
- (8) Teacher-feedback linked all the domains of the chemistry triplet in both combination and decomposition reactions: submicroscopic (visual-spatial elements of the drawing), symbolic (chemical equation), and macroscopic (observations from practical work); whereas peer-feedback linked submicroscopic and symbolic domains for the decomposition reaction.
- (9) Both feedback sources productively used question-posing as a *feedback move* for the decomposition reaction.

11.2 Feedback Features Valuable for Drawing to Learn Chemical Reactions in Large Classes

The following three features of feedback were found useful in supporting drawing to learn chemical reactions as a teaching-learning strategy for large classes (50 students or more).

11.2.1 Conceptual Knowledge of the Feedback Provider

The feedback providers' (i.e., teacher and student-peers) levels of conceptual knowledge influenced the effectiveness of their feedback. The teacher, because of his more advanced level of conceptual knowledge, generated feedback that was more productive than the student-peers for drawing chemical reaction that involved transformation from atoms and molecules to ions. As a result, the teacher-feedback group consistently produced better drawings of these reactions compared to the peer-feedback group during the intervention (revised drawings) and in the post-tests (recall and transfer).

The teacher generated *feedback foci* that demonstrated his advanced level of conceptual knowledge. Firstly, the teacher generated *feedback focus* ideas on the visual-spatial elements of the drawings that student-peers missed during their in-group discussion. These *feedback foci* were challenging for student-peers to generate because they did not possess the same level of conceptual knowledge as the teacher. For the reaction that involved transformation from atoms and molecules to ions (combination), teacher-feedback pointed out ions as particle identity and how to accurately show conservation of particles (visual elements). Teacher-feedback also accurately identified the arrangement of ionic solid (spatial element). Consequently teacher-feedback students in their drawings of combination reaction were able to show particle identity transformation whereas peer-feedback students did not. There were also *feedback foci* ideas from the teacher for the reaction that did not involve transformation from atoms and molecules to ions (decomposition) that student-peers missed.

The teacher, in his feedback, recognized that atoms and molecules do not have charges (visual element). And teacher-feedback distinguished between distances of liquid and gaseous particles (spatial element). The ability of teacher-feedback over peer-feedback to generate those *feedback focus* ideas on the visual-spatial elements during the whole-class presentation echoes the findings of Becker et al., (2015). According to Becker et al., (2015), it is during whole-class presentation that the teacher can direct students' attention towards the essential ideas that students might have overlooked during their in-group discussions.

Secondly, another indication of the teacher's advanced level of conceptual knowledge was his feedback focused on the integration of the visual-spatial elements into the triplet relationship for both reactions involving and not involving particle identity transformation. This task of integrating the chemistry triplet is crucial in learning chemical reactions because it enhances conceptual understanding (Hilton & Nichols, 2011; Yeşiloğlu, 2019). By integrating the chemistry triplet, learners understand that a chemical reaction is a macroscopic phenomenon determined by the structure and interaction of submicroscopic entities; these interactions are represented symbolically as chemical equations.

Thirdly, the teacher focused on a wide range of chemistry concepts that substantiated the other *feedback foci*, i.e., visual-spatial elements and triplet relationship. This wide range of prerequisite chemistry concepts from the teacher may have enriched and/or reactivated students' prior knowledge of chemical reactions. Such enriched and/or reactivated prior knowledge contributed to enhancing the cognitive processes (i.e., selection, organization, and integration) identified by the Generative Theory of Drawing Construction by Van Meter & Garner (2005). Students used the enhanced and/or reactivated prior knowledge to generate better submicroscopic inferences (selection) and its connections to their macroscopic observations and the chemical equation (organization). Consequently, these submicroscopic inferences are expressed as better mental models of the reaction (integration) and then

externalized as visual-spatial elements of the drawings (see Figure 1, Flowchart of the cognitive processes involved in drawing to learn chemical reactions while receiving feedback).

Lastly, the teacher's advanced level of conceptual knowledge enabled him to generate more feedback ideas than the student-peers. This is evident in the greater number of feedback episodes and those *feedback foci* on the visual-spatial elements, triplet relationship and prerequisite chemistry concepts that teacher-feedback generated but peer-feedback missed. This finding differs from Cho and MacArthur (2010) that multiple peer-feedback on writing generates a richer resource of feedback than single expert-feedback. This difference may be because in my study the required level of conceptual knowledge may not have been readily available for the students, particularly in the peer-feedback group. Further according to Cho and MacArthur (2010) such a rich resource of feedback could help assessors detect more problems in an assessee's work. In my study the teacher's advanced level of conceptual knowledge contributed to a richer supply of feedback ideas that enabled teacher-feedback to detect more aspects for improvement in the students' drawings compared to the feedback provided by student-peers (see Chapters 9 and 10 for the quantity and quality of these feedback ideas).

Peer-feedback, despite their developing level of conceptual knowledge, was as equally useful as teacher-feedback in drawing reactions that involved atomic and molecular species remaining as atomic and molecular species (decomposition reaction). The peer-feedback group produced drawings of decomposition reactions that were generally comparable with the teacher-feedback group during the intervention (revised drawings) and in the post-tests (recall and transfer). Student-peers readily recognized 'atoms' and 'molecules' as particle identities and conservation of particles (visual elements) for this reaction that did not involve particle identity transformation. It is indeed consistent with the

findings of Harrison & Treagust (1996) that students prefer to think of atoms as concrete, discrete entities (making up matter) and not involving abstract process ideas (e.g., electron transfer). This is because students experience fewer challenges in using the particle model of reaction compared to the atomic model (Cheng, 2018; Cheng & Gilbert, 2017). Additionally peer-feedback recognized how to scientifically draw substances in the liquid phase, i.e., scattered and with solvent particles surrounding solute particles in aqueous solution (spatial element). Also peer-feedback readily distinguished between particle arrangement of solid and gaseous substances. Distinguishing between closely packed solid particles (no empty spaces in-between) and widely separated gaseous particles (wide empty spaces in-between) appeared to be less challenging for the students than distinguishing between liquid and gaseous particles (both have empty spaces in-between). Notably student-peers although they did not link all the three domains of the triplet relationship, did link the symbolic (chemical equation) and submicroscopic (visual-spatial elements of the drawing) for the decomposition reaction. This finding on the difficulty of students to link the macroscopic observations of the reaction to its symbolic (chemical equation) and submicroscopic (visual-spatial elements of the drawing) representations confirms that the task of integrating the chemistry triplet is indeed challenging for students (Taber, 2018a).

11.2.2 Explanations and Posing Questions were the Most Productive Feedback Moves

Teacher-feedback and peer-feedback used distinct productive *feedback moves*. Predominantly the teacher, given his advanced level of conceptual knowledge and pedagogical content knowledge, used explanations whereas student-peers who have developing level of conceptual knowledge used question-posing.

The two groups' delayed post-test achievement may be attributed to the productive use of these two *feedback moves*. The teacher's frequent use of explanations was particularly helpful for learning the reaction that involved transformation of particles from atoms and

molecules to ions. Teacher-feedback students did better on this type of reaction for both recall and transfer tests a month after the intervention compared to peer-feedback students. This result of the delayed post-tests suggest that teacher-feedback students really paid attention and learned from the explanations as they were able to apply the feedback ideas even a month after the intervention. The findings on the teacher's frequent use of explanations as a *feedback move* and his extensive *feedback foci* on the visual-spatial elements agree with previous studies that the teacher's advanced level of conceptual knowledge enable him/her to provide longer explanations and more ideas during feedback (Cho & MacArthur, 2010; Cho et al., 2006; Gielen et al., 2010a; Tsivitanidou et al., 2011).

Synthesis of previous studies provide evidence on the mechanism of how explanations during teacher-feedback supported recall and transfer of learning. Barnett and Ceci (2002) conceptualized that transfer of learning involves three steps: (1) recognizing the relevance of acquired knowledge, (2) recalling the knowledge, and then (3) applying the knowledge to the new context. The first two steps involve retention while the third step involves understanding. Hence transfer of learning requires understanding that begins with retention. My quantitative results support this conceptualization of Barnett and Ceci (2002). Teacher-feedback supported the two levels of learning, i.e., recall (low-level) and transfer (high-level) the same way as demonstrated by the similar results in the two post-tests where the teacher-feedback group did better than peer-feedback group (see Table 47). The similar order of difficulty in drawing the reaction types in the two post-tests (see Table 46), where drawing decomposition reactions was the least challenging followed by combination reactions while displacement reactions were the most challenging both in the recall and transfer tests.

Explanations also help students recognize the important properties of a concept (Corral & Carpenter, 2020). Doing so allows students to spend more time processing or

expanding the concept (Rich et al., 2017). Consequently, the explanations expedite the integration of the concept into memory, promote a better understanding of it, and facilitate its retrieval and application to a new context (Butler et al., 2013; Rich et al., 2017). In my study, teacher-feedback students drew ions as particle identity because the teacher explained it in his feedback unlike peer-feedback students who overlooked it in their feedback and drawings. As a result, teacher-feedback students were supported to retain and understand these ideas and subsequently allowed for better transfer, i.e., drawing the new set of reactions.

Students' posing questions to each other as the predominant peer-feedback *move* in my study is consistent with previous studies that found students often ask for more clarification and elaboration during feedback (Cho et al., 2008; Cho & MacArthur, 2010; Cho, Schunn, & Charney, 2006). Students' frequent use of questions was as productive as the teacher's explanations of the reaction where they demonstrated adequate conceptual knowledge, i.e., the reaction that involved atoms and molecules remaining as atoms and molecules (i.e., no particle identity transformation). For this type of reaction, peer-feedback group's scores in the post-tests, i.e., recall and transfer, were comparable to the teacher-feedback group. Also, the teacher-feedback group although they produced better revised drawings of decomposition reaction during the intervention than the peer-feedback group, the difference was only modest.

Synthesis of previous studies offers an explanation to the mechanism of posing and answering questions in supporting learning where students have adequate level of conceptual knowledge. According to Alexander et al., (2022), the relationship between questioning and learning/understanding is mediated by thinking. When students ask questions to each other, those questions serve as stimulus to spark each other's thinking that leads to learning and understanding. It is during thinking where students actively construct knowledge by building meanings to the new information based on their existing prior ideas (Chin & Osborne, 2008)

or make changes to the existing prior ideas in the light of the new information (Chouinard, 2007). In my study, students posing and answering questions about the reaction that involved atoms and molecules remaining as atoms and molecules may have stimulated thinking among themselves. And they may have used their prior knowledge of the particle model of the reaction (Cheng, 2018; Cheng & Gilbert, 2017) to make sense of the shared ideas.

11.2.3 Student's Cognitive Engagement with Feedback

The ICAP framework (Chi, 2009, 2021; Chi & Wylie, 2014) was useful to describe students' cognitive engagement with the two feedback sources. Teacher-feedback was regarded as *active* and peer-feedback as *interactive*, which is at a higher engagement level than *active*. The ICAP framework posited two conditions for an *interactive* engagement and were both observed during peer-feedback: (1) the students' interaction was *constructive*, i.e., aimed at generating knowledge not previously available to them through drawing. And (2) there was sufficient degree of turn-taking in their roles as assessees and assessors. More so, the students (just like their teacher), while taking turns, utilized three additional *feedback moves* (i.e., identifying, explaining, and affirming an idea) that were not initially provided to them (i.e., adding, removing, revising, and finding out more about an idea). The use of these new *feedback moves* suggests that during the intervention, students did not just provide feedback ideas while passively following the teacher's instruction. Instead there were interactions among the students and exchanges of feedback ideas. Also the students' use of the three additional *feedback moves* indicates that despite their developing level of conceptual knowledge, they did think for themselves and used their own judgement in evaluating their peers' drawings. Moreover, this finding on the three new *feedback moves* adds to the four scaffold prompts, i.e., adding, removing, revising, and finding out more about an idea (these were the same prompts that I adapted for my study) that Windschitl et al. (2018) suggested were used by scientists to improve scientific models.

With feedback on drawing chemical reactions as the context of instruction, my study found that an *active* student engagement with teacher-feedback, although at a lower cognitive engagement level was generally more productive than *interactive* peer-feedback. This finding was not consistent with the order of learning predicted by the ICAP framework (Chi, 2021, 2009, and Chi & Wylie, 2014) and with the assumption that an inferior engagement mode like *Active* does not help students see the deep structures of a concept (Chi & VanLehn, 2012). This inconsistent finding with the ICAP hypothesis is likely because the students who are the feedback providers have a developing level of conceptual knowledge. Student cognitive engagement during peer-feedback, although higher than teacher-feedback, did not generally result in better drawings. Conversely, it was the *active* engagement with expert feedback that helped students produce better drawings of the challenging reactions. This finding offers additional support to El-Mansy et al., (2022) as to why *interactive* engagement did not lead students to provide the scientific answers and with Thurn et al., (2023) as to why better learning can still be expected from a lower cognitive engagement level. My study showed that a lower engagement level (*active*) during feedback can potentially be productive if the feedback provider has the required level of conceptual knowledge. Teachers should be cautious in implementing *interactive* peer-feedback on a conceptually-challenging task. It should be a pertinent consideration that students possess the appropriate level of understanding of the associated conceptual ideas when they engage with peer-feedback. For large classes where implementing *interactive* peer-feedback to support drawing to learn reactions is a challenge, *active* student engagement paired with expert feedback can be useful.

It is however acknowledged that *interactive* teacher-feedback may also potentially support drawing to learn and is envisaged to contribute to better learning outcomes than *active* teacher-feedback. Yet *interactive* teacher-feedback would be challenging to implement

in large classes like those in the Philippines. During teacher-feedback there may be few opportunities for exchanges between students and the teacher. However, since typical class sizes are large, teachers will tend to ask students to either work together and give peer-feedback or receive teacher-feedback *actively*.

The intervention supported the students in large classes to develop their skills in giving feedback to drawings. The design of the intervention simulated the likely typical implementation of feedback on drawing as a teaching-learning strategy for large classes. The students demonstrated productive feedback skills for drawing the reaction when they have adequate level of conceptual knowledge (for the reaction that did not involve ions). The provision of the rubric provided the structure for an *interactive* exchange during peer-feedback. The criteria in the rubric identified the aspects, i.e., visual-spatial elements of the drawings, to focus their feedback ideas (*feedback foci*). The scaffold prompts provided the initial cues that guided the students how to deliver (*feedback moves*) those feedback ideas. Nonetheless it may be more productive for the student-peers if the training time for giving feedback is extended. It appeared from the findings that students needed more time and opportunities to develop the conceptual knowledge for the reaction that involved ions (more challenging reactions). This reflection on extending the training time for giving feedback resonates with Sadler's (2009) remark that the capacity to evaluate and give feedback to another student's work takes time and this is likely because conceptual knowledge crucial to feedback takes time to develop.

Chapter 12 Conclusions, Implications and Limitations

This chapter presents the conclusions of my study and its implication for teaching, learning and future research work. The limitations of the study are also described together with suggestions for further work.

12.1 Conclusions

Order of difficulty in drawing reactions between the two feedback sources

This study started with the thinking that some reaction types are easier than others to represent through drawing at the submicroscopic level. Given this, the first research question that my study asked was: *Is there a difference in the order of difficulty in drawing chemical reactions?* When I conceptualised this study, based on the idea that reactions involving spatial rearrangement atoms were easier than those involved ions or electron transfer, it was predicted that drawing decomposition reaction (e.g., H_2O_2 to $\text{H}_2\text{O} + \text{O}_2$) was the easiest. This was followed by combination (e.g., $\text{Mg} + \text{O}_2$ to form MgO), single displacement (e.g., $\text{Mg} + \text{CuCl}_2$), and double displacement (e.g., $\text{Na}_2\text{S} + \text{HCl}$). I answered the question by testing two classes, one receiving either teacher-feedback and the other peer-feedback to support students to draw. Students in groups performed practical work on the different types of reactions: combination ($\text{Mg} + \text{O}_2$), decomposition (H_2O_2 to $\text{H}_2\text{O} + \text{O}_2$), single displacement (i.e., $\text{Mg} + \text{CuCl}_2$), and double displacement (i.e., $\text{Na}_2\text{S} + \text{HCl}$). Then they drew submicroscopic level representations of each of the reactions. After receiving feedback from either the teacher or their peers, students revised their drawings. The revised drawings were assessed using a visual-spatial rubric that was developed for this study.

The findings demonstrated that regardless of whether the teacher or the peers gave the feedback, there is a general trend in the order of difficulty of reaction types. The trend during the intervention was the same as my initial conceptualisation. Drawing decomposition was the easiest then followed by the combination reaction. And drawing displacement reactions

was the most challenging. Moreover, drawing single displacement (i.e., $\text{Mg} + \text{CuCl}_2$) was easier than double displacement reaction (i.e., $\text{Na}_2\text{S} + \text{HCl}$) as initially predicted. However, this was not always the case in the transfer test a month after the intervention; drawing another single displacement reaction (i.e., $\text{Ca} + \text{H}_2\text{SO}_4$) was found to be more challenging than another double displacement (i.e., $\text{CaCl}_2 + \text{KOH}$).

A more in-depth analysis of students' drawings using the visual-spatial rubric identified that such difficulty was not entirely based on the reaction types but on the features of the particles involved in the reactions. Drawing reactions involving atoms and molecules (non-charged particles) were less challenging than those involving ions. This is consistent with the idea that the particle model of reactions (i.e., reactions involving simple rearrangement of atoms) is more intuitive and less challenging than the atomic model of reactions (i.e., reactions involving conversions between atoms and ions). The analysis identified subtlety among reactions that involved ions. The following were identified for reactions involving ions:

- (1) The difficulty varies depending on the features of the ions, i.e., whether they are monatomic or polyatomic (e.g., Cl^- or SO_4^{2-}). It was less challenging to draw monoatomic than polyatomic ions.
- (2) For reactions involving monatomic ions, the difficulty differs based on two features:
 - (a) The number of ionic species involved in the reaction. I found that as the number of monatomic species increased, the reactions became more challenging to draw. For example, drawing the combination reaction: $2\text{Mg}_{(\text{s})} + \text{O}_{2(\text{g})} \rightarrow 2\text{MgO}_{(\text{s})}$ was easier than the single displacement reaction: $\text{Mg}_{(\text{s})} + \text{CuCl}_{2(\text{aq})} \rightarrow \text{Cu}_{(\text{s})} + \text{MgCl}_{2(\text{aq})}$. The combination reaction involved only two ionic species: Mg^{2+} and O^{2-} whereas the single displacement reaction involved three ionic species: Mg^{2+} , Cu^{2+} and Cl^- .

(b) The charge of the ions in the compound. Students tend to assign a magnitude of charge of 1 (+/–) to ions. Hence drawing an ionic compound where both ions have a charge of 1 (+/–) (e.g., Na^+ and Cl^- in NaCl) was the easiest. This is followed by ionic compound where only one of the two ions had a charge of 1 (+/–) (e.g., Cu^{2+} and Cl^- in CuCl_2). Drawing an ionic compound where neither ion had a charge of 1 (+/–) (e.g., Mg^{2+} and O^{2-} in MgO) was the most challenging and this is probably because students thought that Mg and O have a charge of 1+ and 1– due to the ion ratio of 1:1.

These two features of reactions involving monoatomic ions work in tandem. A reaction can be more challenging than another because it involved more ionic species and because those ionic species have a charge of not 1 (+/–). Consider the combination reaction, $2\text{Na}_{(\text{s})} + \text{Cl}_{2(\text{g})} \rightarrow 2\text{NaCl}_{(\text{s})}$ and single displacement reaction, $\text{Mg}_{(\text{s})} + \text{CuCl}_{2(\text{aq})} \rightarrow \text{Cu}_{(\text{s})} + \text{MgCl}_{2(\text{aq})}$. Drawing the single replacement is envisaged to be more challenging because it involved three ionic species Mg^{2+} , Cu^{2+} and Cl^- , and two of them have a charge of not 1 (+/–) whereas the combination reaction involved only two ionic species, each with a charge of 1 (+/–), i.e., Na^+ and Cl^- .

(3) For reactions involving polyatomic ions, the difficulty varies depending on:

(a) The number of constituent atoms in the ion (e.g., OH^- has one atom each of O and H while SO_4^{2-} has one S atom and four O atoms). Drawing polyatomic ions with no subscript in their formula (e.g., OH^- , which has only one of each constituent atom) was less challenging than those with subscripts (e.g., SO_4^{2-} , which has one S and four O atoms). Some students confused the subscript as not the number of the constituent atom in the polyatomic ion (4 O atoms in the SO_4^{2-} ion) but as the number of polyatomic ions (4 SO_4^{2-} ions); and

(b) The charges of the ions. Some students tend to assign '1+' or '1-' as the charge of ions. Their practice worked for ions with a single charge such as Na^+ or OH^- . But assigning a one-negative charge to sulfate ions misrepresented its charges as being 2- (i.e., SO_4^{2-}).

This subtlety among reactions involving ions explains the difficulty of drawing the different reaction types. The decomposition reaction (i.e., H_2O_2 to $\text{H}_2\text{O} + \text{O}_2$) was the easiest to draw because the particles involved were atoms and molecules. The combination (i.e., $\text{Mg} + \text{O}_2$ to form MgO) was less challenging to draw than the displacement reactions because the combination reaction involved a smaller number of ions. Based on reaction types, I had assumed that double displacement (i.e., $\text{CaCl}_2 + \text{KOH}$) was more complex than single displacement reaction (i.e., $\text{Ca} + \text{H}_2\text{SO}_4$) (in the transfer test). But empirical data demonstrated that this was not always the case. The single displacement was found to be more difficult to draw than the double displacement reaction. The single displacement reaction involved SO_4^{2-} , which was more challenging to draw (due to the number of its constituent atoms and the magnitude of the overall charge) than OH^- in the double displacement reaction.

This study developed a tentative guide for the difficulties of different types of reactions based on the chemical species involved in them. However, I acknowledge that this guide is not exhaustive. For example, the findings revealed that ionic compounds with the charge of 1+ and 1- (e.g., NaCl with ion ratio of 1:1) are the least challenging to draw followed by compounds of 2+/1- (e.g., MgCl_2 with ion ratio of 1:2). Then compounds with the charge of 2+/2- (e.g., MgO still with ion ratio of 1:1) were the most difficult. Yet it cannot be known from my data the students' difficulties in drawing ions with charges that are not directly shown from the ion ratio in the compound, e.g., PbO_2 with ion ratio of 2:1 but

charges are Pb^{4+} and O^{2-} . Despite the unknown it does not affect the conclusion that features of ions play a key role in determining the difficulties of representing reactions at the submicroscopic level, which go deeper than the types of reactions.

Feedback features that are valuable in drawing to learn

The second research question of this study was: *Is there a difference between the quality of students' drawings in the teacher-feedback group and peer-feedback group?* In general, those who received teacher-feedback represented the reactions at the submicroscopic level better than those who had peer feedback. Yet, depending on the complexity of the reaction, the efficacy of the two feedback sources differed. Teacher-feedback supported students in producing better drawings of the more challenging reactions, i.e., combination, single displacement, and double displacement in both recall and transfer tests. The teacher supported students to draw ions (as a particle identity) and the particles of substances in the solid state. Yet both groups struggled in differentiating between particles of substances in the liquid and gas states. Peer-feedback fared similarly with teacher-feedback for supporting students' drawings of the easier reaction, i.e., decomposition, in the recall and transfer tests. The student-peers, just like the teacher, supported students to draw atoms and molecules (as particle identities). To gain insights into the conditions that contributed to the quality of drawing the different reaction types, the features of the two feedback sources were examined. These features are discussed as answer to the next research question.

The third research question that my study answered was: *What are the features of feedback that are valuable for supporting drawing to learn chemical reactions?* It is not controversial that teachers have a stronger content knowledge and hence could provide better feedback. This third research question was answered by comparing the *foci* and *moves* of teacher's and peer's feedback. *Feedback foci* refer to the ideas associated with the drawing task where the feedback was focused. *Feedback moves* describes how the *feedback focus*

ideas were delivered. This study identified exactly the way that teacher-feedback fared better than peer-feedback in supporting the drawing of reactions. This effectiveness of teacher feedback can be attributed to the following features:

- (1) The *feedback foci* of the teacher generated more feedback ideas than peer-feedback.

These *teacher-feedback focus* ideas include (a) recognising the formation or transformation to ions and its representation as visual and spatial elements of the drawings, (b) linking the chemistry triplet, and (c) explaining prerequisite chemistry concepts that substantiated the other feedback ideas. Nevertheless, the quality of drawings of reaction involving ions after receiving teacher-feedback dropped more than those who received peer-feedback a month after the intervention. This suggests that the effect of teacher-feedback on drawing the more complex reactions faded over time.

- (2) The predominant use of explanations as a *feedback move*. The teacher's explanations may have supported the students' recall and transfer of learning a month after the intervention. Transfer of learning requires retention and then understanding (Barnett & Ceci, 2002). The explanations substantiated the *feedback focus* ideas, which may have allowed more time for students to process those ideas. Consequently, this may have helped them retain those ideas and gained better understanding, which then facilitated better recall and transfer (drawing reactions they have not encountered during the intervention).

Students had the required conceptual knowledge for the easier reaction. So, they generated *feedback focus* ideas that were equally useful as the teacher-feedback. Though, they did not often use explanations, students often utilised question-posing as productive *feedback move*.

- (1) *Peer-feedback focus* ideas included how to accurately show the visual and spatial elements. Just like the teacher, the students in their feedback recognised atoms and molecules as particles involved in the reactions (visual) and arrangement of liquid particles as irregularly scattered (spatial). Peer-feedback did not focus on linking the chemistry triplet, but it linked the submicroscopic (visual and spatial elements of the drawing) to the symbolic (chemical equation).
- (2) It was evident from students' *feedback focus* ideas that they have knowledge on using the particle model of reactions. And posing questions as a *feedback move* may have helped peer-feedback fared equally with teacher-feedback in the recall and transfer test for this reaction. Students asking questions to each other, just like the teacher's explanations, may have allowed them additional time to engage with their *feedback focus* ideas, retain them and consequently apply them in drawing the easier reaction that were unfamiliar to them (transfer).

On drawing the spatial elements of the reactions (i.e., how the represented particles are arranged and distance between them) teacher-feedback explained in his *feedback focus* ideas the regular arrangement of the particles of metallic and ionic crystalline solids; whereas peer-feedback only recognised solid metallic particles as regularly arranged. Consequently teacher-feedback students drew reactions involving solid substances better than peer-feedback students. Both feedback sources also recognised the irregularly scattered arrangement of liquid particles. For distance between particles, peer-feedback in its *feedback focus* ideas incorrectly described the distance between liquid particles as widely separated; while teacher-feedback accurately distinguished between liquid (close to each other) and gas (widely separated) particles. Yet students from both feedback groups struggled in representing the distances of particles of liquid and gaseous substances in their drawings. Both groups tend to represent liquid and gas particles similarly as either widely separated or

close to each other. Peer-feedback, having not mentioned that liquid particles are close to each other, suggests that this knowledge may not be available to the students. Rather the alternative conception that liquid particles have big empty spaces between them seemed to be strongly held by the students. And this alternative conception was resistant to conceptual change even after the teacher had already explained in his feedback the accurate distinction between the distance of liquid and gaseous particles.

The students' cognitive engagement with feedback during the intervention was characterised using the ICAP framework. Teacher-feedback was regarded as *active* and peer-feedback was *interactive*. Yet, the expected order of learning posited by the ICAP framework was not observed in this instructional context. My findings showed that during feedback on drawing reactions, *interactive* engagement during peer-feedback was not as productive as *active* engagement with teacher-feedback. This is likely because the students as feedback providers lack the required level of conceptual knowledge. In contrast, a lower student engagement (*active*) coupled with expert feedback was more productive. It appears that for an instructional task that is conceptually challenging, i.e., feedback on drawing reactions, higher cognitive engagement does not always guarantee better learning. This finding contributes to the application of the ICAP framework on feedback as an instructional context by qualifying the level of conceptual knowledge of the feedback providers.

The students in this intervention study had training on how to provide feedback on drawing reactions. The training involved providing them with the criteria for evaluating the drawings (to guide their *feedback foci*) and prompts on how to deliver their feedback (to guide their *feedback moves*). The teacher also modelled how to use the criteria and prompts in giving feedback with opportunities for students to ask questions. The students had four lessons to practice how to give feedback using the criteria and prompts. Nevertheless, it appears that the provided training was not sufficient for student-feedback to be as productive

as expert-feedback. It is however acknowledged that it is possible that the practice of providing feedback was not long enough for students to fully develop their feedback skills. Students may have needed more time and practice. In using peer-feedback and/or asking students to engage interactively, the teacher should ensure that the students possess the required conceptual knowledge and that they are adequately trained to provide useful feedback.

12.2 Implications for Teaching and Learning

Meaningful learning from a constructivist viewpoint involves making connections between prior knowledge and the new information, that is, using existing understanding to make sense of the new experience (Taber, 2011). The findings on the order of difficulty in drawing reactions offers an important implication to teaching, particularly in the sequence of teaching and learning reactions at the submicroscopic levels. Chemistry teachers may begin with those that involved atomic and molecular species since students' prior knowledge on this is readily available. Then, building from this, ions and particle identity transformation can be introduced. Subsequently, to increase complexity of the reaction, the features of the ions can be varied progressively. For example, teaching and learning reactions involving ions can begin with just monatomic ions with $1+$ and $1-$ charges, and 1:1 ratio in the compound (e.g., $\text{Na}^+ + \text{Cl}_2$ to form NaCl). I give this example also because the reaction is readily observable to students. Then ionic compounds where only one of the two ions had a charge of 1 (+/-) and therefore an ion ratio of not 1:1 (e.g., $\text{Cu} + \text{Cl}_2$ to form CuCl_2 has an ion ratio of 1:2) can be used. This can be followed by ionic compounds where neither ion had a charge of 1 (+/-) but an ion ratio of 1:1 (e.g., $\text{Mg} + \text{O}_2$ to form MgO). From here reactions involving polyatomic ions can be introduced, starting from those with no subscripts then with subscripts within the polyatomic ion. Chemistry teachers should note that in teaching chemical reactions, students need more support in learning ions as particles involved in a reaction.

Previous studies have identified student-feedback as a potential alternative for teacher-feedback in large classes where giving regular and detailed feedback is a challenge. This is because student-feedback allows timely feedback and fair feedback provision for each student. It also facilitates student interaction (highest cognitive engagement) that may lead to the generation of new understanding. However, for a conceptually-challenging task, it seems that student-feedback cannot generally be a potential substitute for teacher-feedback. For such a learning task like drawing reactions, the feedback provider needs to have the required level of conceptual knowledge. So, teacher-feedback coupled with opportunities for students to engage *actively*, e.g., how it was implemented in my intervention, can be a useful approach to support students' drawing to learn reactions. Also, the findings of my study on the *feedback focus* ideas that peer-feedback missed, identified the pertinent conceptual ideas that students do not possess and so they may need to learn before asking them to draw chemical reactions. Knowledge of these conceptual ideas may improve students' use of questions during peer-feedback. These conceptual ideas are: (1) recognise ions (and their complexities) as particle identities and apply particle conservation for the more challenging reactions (visual elements), (2) distinguish among the arrangement and distance of the three states of matter particularly between liquid and gaseous particles (spatial elements), and (3) link these visual-spatial elements (submicroscopic ideas) to the chemical equation (symbolic representation) and to the observations from the practical work (macroscopic observations).

12.3 Limitations of the Study and Recommendations for Future Work

The limitations of my study are about: (a) freehand drawing as a representational tool, and (b) the choices in the methodology, i.e., research design, instrument, procedure, control variables and context. The findings are conditional based on these limitations. For each limitation, a suggestion for future work is stated.

1. The study did not investigate the extent to which the students made specific changes in their drawings based on the feedback provided by either the teacher or their peers due to time constraints. The current work compared the quality of ~2,200 drawings after receiving feedback. Further work can be done by comparing the quality of unrevised and revised drawings. Then interviews can be conducted, or a questionnaire can be administered, to identify the extent to which students implemented the feedback that they received. The affective side of giving and receiving feedback can also be investigated. Students can be asked about their level of acceptance of teacher-feedback and peer-feedback relative to how they view the competence level of their assessors.
2. Students drew freehand their submicroscopic understanding of chemical reactions from practical work. A three-dimensional dynamic phenomenon was reduced into a two-dimensional static representation. Unlike computer drawing, freehand drawing cannot directly show a dynamic visualisation of the chemical reaction at the submicroscopic level. Dynamic temporal processes like identity transformation, electron transfer, and particle rearrangement were shown as changes in the visual and spatial elements in a before-and-after condition. These dynamic processes, represented as visual and spatial elements of the drawings, influence the complexity of the reactions. Future work can explore the outcomes of the intervention (i.e., using feedback on drawing) if chemical reaction (a three-dimensional dynamic phenomenon) is directly shown as a three-dimensional representation.
3. Freehand drawing of chemical reaction from the practical work involved the translation from the macroscopic domain to the submicroscopic domain. Students' ability to translate chemical reactions at the macroscopic level to two-dimensional static drawings at the submicroscopic level was constrained by the identified features

of the visual and spatial elements. Examples of such features include discrete circles, bonded pairs of circles, colours of the circles, annotations, labels, regular or irregular arrangement of the circles, and spaces between the circles. Further work can consider supporting students to incorporate other features of the visual and spatial elements. Students' ability to incorporate these additional features can advance their ability to account for other aspects of a chemical reaction. Additional features, like size of circles, and shapes and angles between bonded circles, can help students to represent atomic or ionic size, and geometry of molecules, respectively. These conceptual ideas are important in understanding chemistry topics like bonding and structure.

4. As a quasi-experimental study, intact classes were used to set up the experimental groups (though a coin toss was used to randomly assign the experimental conditions). A random control trial was not utilised. The use of intact classes contributed to the ecological validity of the intervention because the study most likely emulated real-world conditions. In implementing the intervention in a real-world context, a teacher is likely to have intact classes rather than a randomly sampled class. Nevertheless, future researchers can do random sampling. Using random sampling can increase the comparability of the experimental groups and consequently the generalizability and robustness of the findings.
5. Not all feedback episodes generated by the teacher and students could be directly interpreted. There were those meanings that were subtle. An example is the peer-feedback on Student 3's drawing (Figure 100 in Section 10.4.2). The feedback is interpreted as a comment about the macroscopic observation. Though there could be other associated conceptual ideas, these cannot be surmised because of the missing words from the recording. So, the researcher's (and the second rater to some extent) best judgement was utilised to surmise the meaning and code the feedback episodes.

The researcher was in an appropriate position to interpret the meaning of the feedback episodes. The researcher was present during the whole implementation of the intervention. The researcher is a Filipino and had been teaching chemistry in the Philippines for many years. The researcher is familiar with the teaching-learning context. It is however suggested that in future work interviews with the teacher and students be conducted. The interview will allow the teacher and students to explain what exactly they meant with their feedback statements.

6. This quasi-experimental study considered the following as control variables: the teacher, students' prior knowledge, students' spatial ability, time of teaching, and the physical conditions of the classroom (i.e., ventilation, lighting, seating arrangement, and noise quality). These control variables were either kept consistently the same for the two experimental groups or their effects were removed during the quantitative analysis. However, I acknowledge that there might be other control variables that can potentially impact the results and were not considered in the current work. Examples can be the communication skills of the teacher and students, collaboration skills of students, and/or the teacher and students' prior experience of implementing drawing and feedback (the sample in this study did not have prior experience). Future work can consider these other control variables.
7. The intervention was implemented in the Philippines, among Filipino students and their teacher. Findings are delimited by the Philippine (and Asian) context. The research work can be extended by exploring its outcomes in a different learning environment. The intervention can be replicated or adapted in different teaching-learning contexts where learning is less teacher-led.
8. The study did not analyse the levels or types of questions that the teacher and students generated during their feedback. The present work looked at the feedback *foci* and

feedback moves used. Question-posing has been identified as one of the seven *feedback moves* used by the teacher and students to convey their feedback. Further work can investigate the levels or types of questions posed and how they relate to the quality of feedback and drawings generated.

9. The study did not explore how students' roles as assessors and assessees impact the quality of their drawings during peer-feedback. Being an assessor for others' drawings might have influenced how students learned from their feedback. By identifying the strengths and weaknesses of their peers' work, they can evaluate their work (Hill & Edwards, 2019; Hovardas et al., 2014; Li et al., 2010; Tsivitanidou et al., 2011). Further research can explore the effects of students being an assessor for their peers' drawings and their learning from giving feedback.
10. The study was conducted with only two classes and one chemistry teacher. Although the teaching-learning conditions in the two classes are typical in Philippine classrooms, it is acknowledged that due to the small sample size, the results of the study are not generalisable to the larger populations.

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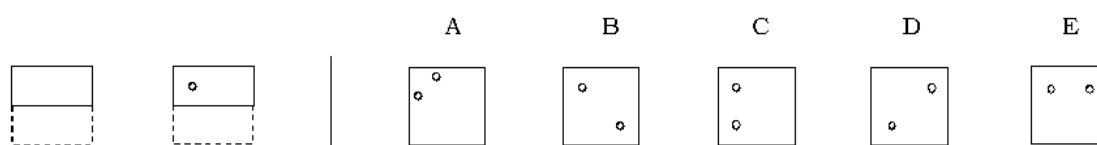
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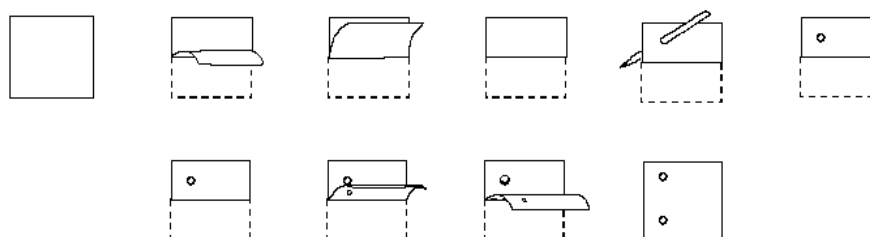
Appendix A Paper Folding Test

In this test you are to imagine the folding and unfolding of pieces of paper. In each problem in the test there are some figures drawn at the left of a vertical line and there are others drawn at the right of the line. The figures at the left represent a square piece of paper being folded, and the last of these figures has one or two small circles drawn on it to show where the paper has been punched. Each hole is punched through all the thicknesses of paper at that point. One of the five figures on the right of the vertical line shows where the holes will be when the paper is completely unfolded. You are to decide which one of these figures is correct and draw an X through that figure.

Now try the sample problem below. (In this problem only one hole was punched in the folded paper).



The correct answer to the sample problem above is C and so it should have been marked with an X. The figures below show how the paper was folded and why C is the correct answer.



In these problems all of the folds that are made are shown in the figures at the left of the line, and the paper is not turned or moved in any way except to make the folds shown in the figures. Remember, the answer is the figure that shows the positions of the holes when the paper is completely unfolded.

Some of the problems on this sheet are more difficult than others. If you are unable to do one of the problems, simply skip over it and go on to the next one.

You will have three minutes for each of the two parts of this test. Each part has one page. When you have finished Part One, STOP. Please do not go on to Part Two until you are asked to do so.

DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO

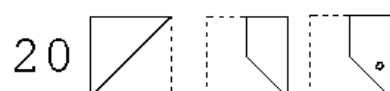
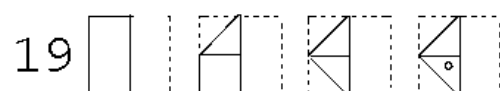
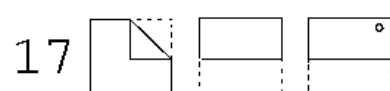
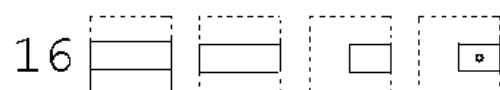
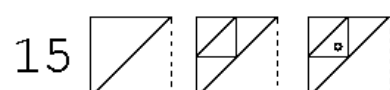
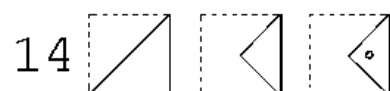
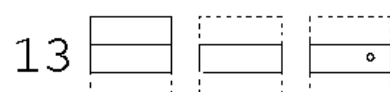
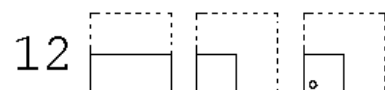
PART ONE (3 MINUTES)

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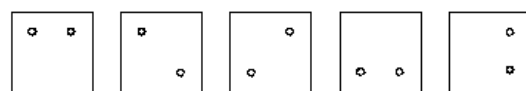
STOP

DO NOT PROCEED TO THE NEXT PAGE UNTIL ASKED TO DO SO

PART TWO (3 MINUTES)



A B C D E



STOP AND WAIT FOR FURTHER INSTRUCTIONS
DO NOT GO BACK TO PART ONE

Appendix B.1 Prior Knowledge Test

Name: _____ Score: _____

Grade and section: _____ Date: _____

Age: _____ Gender: _____ Team No. _____

Multiple-choice test. Please read each question and response options carefully, and then choose the one BEST option. Write the letter of your answer in the space provided before each item.

_____ 1. Which of the following symbols indicates that a substance is dissolved in water?

a. (s)	c. (w)
b. (l)	d. (aq)

_____ 2. What happens when solid sodium chloride is dissolved in water?

- a. It will dissociate into separate ions – sodium ion and chloride ion.
- b. It will remain as an intact sodium chloride compound.
- c. It will form sodium chloride molecules.
- d. It will not mix with water.

_____ 3. Which of the following is an element?

a. Magnesium chloride	c. Magnesium chloride solution
b. Magnesium	d. Magnesium alloy

_____ 4. Which of the following is a compound?

a. Copper chloride	c. Copper chloride solution
b. Copper	d. Copper alloy

_____ 5. Which of the following is a metal?

a. Cl	c. Ca
b. C	d. O

- _____ 6. What happens to non-metal atoms when they chemically combine with a metal atom?
- a. Non-metal atoms lose electrons and become positive ions.
 - b. Non-metal atoms gain electrons and become negative ions.
 - c. Non-metals remain electrically neutral.
 - d. None of the above.
- _____ 7. Which of the following statements best describes an electron?
- a. Electrons are negatively charged subatomic particles located in the nucleus.
 - b. Electrons are negatively charged subatomic particles surrounding the nucleus.
 - c. Electrons are positively charged subatomic particles located in the nucleus.
 - d. Electrons are positively charged subatomic particles surrounding the nucleus.
- _____ 8. Which of the following statements is NOT TRUE?
- a. Protons have a positive charge and are located in the nucleus of an atom.
 - b. The nucleus is made up of protons and electrons
 - c. The nucleus is made up of protons and neutrons.
 - d. The charge of the nucleus is positive.
- _____ 9. Magnesium has an atomic number of 12 and a mass number of 24, therefore magnesium atom is composed of?
- a. 12 protons and 12 electrons.
 - b. 12 protons and 24 neutrons.
 - c. 24 protons and 12 electrons.
 - d. 12 protons and 36 neutrons.

_____ 10. Chlorine has 17 protons and 18 neutrons. What are the atomic number and mass number of a chlorine atom?

- a. The Atomic number is 17, Mass number is 18
- b. The Atomic number is 17, Mass number is 35
- c. The Atomic number is 18, Mass number is 17
- d. The Atomic number is 35, Mass number is 18

_____ 11. Which of the following determines the chemical behaviour of an atom?

- a. Number of protons in the nucleus of the atom
- b. Number of electrons in the outermost shell
- c. Number of electrons in the innermost shell
- d. Size of the electron cloud

_____ 12. If an atom gains extra electrons making its outermost shell full, what happens to the atom?

- a. Its charge becomes positive.
- b. Its charge becomes neutral.
- c. It becomes unstable.
- d. It becomes stable.

_____ 13. Which subatomic particle is transferred during ionic bonding?

a. Innermost electrons	c. Innermost protons
b. Outermost electrons	d. Outermost protons

_____ 14. Using the periodic table, how many valence electrons does Calcium have?

a. 1	c. 3
b. 2	d. 4

- _____ 15. For bromine to assume a stable electron configuration like that of a noble gas (krypton), how many electrons does it need to gain?
- a. 1
 - b. 2
 - c. 3
 - d. 4
- _____ 16. Which of the following has an ionic bond?
- a. Cl_2
 - b. Na
 - c. NaCl
 - d. CCl_4
- _____ 17. Which of the following best describes a metallic bond?
- a. It is a type of ionic bond.
 - b. It is a type of covalent bond.
 - c. It is formed by the attraction between a positive ion and electrons.
 - d. It is formed by the attraction between a positive ion and a negative ion.
- _____ 18. Which of the following BEST describes the outermost electrons in a metallic bond?
- a. They are shared between two adjacent metal atoms.
 - b. They move freely throughout the network of metal atoms.
 - c. They are constantly moving from one energy level to another.
 - d. They are held strongly by the most positively charged metal atom.
- _____ 19. What is the correct charge and name of the ion formed by Calcium?
- a. 1+, cation
 - b. 1-, anion
 - c. 2+, cation
 - d. 2-, anion
- _____ 20. What is the correct charge and name of the ion formed by Fluorine?
- a. 1+, cation
 - b. 1-, anion
 - c. 2+, cation
 - d. 2-, anion

- _____ 21. Which of the following will NOT form ions in an aqueous solution?
- a. MgCl_2
 - b. NaI
 - c. $\text{C}_6\text{H}_{12}\text{O}_6$
 - d. KBr
- _____ 22. Sodium chloride is formed when a sodium ion (Na^+) is attracted to a chloride ion (Cl^-). Which of the following BEST characterizes sodium chloride?
- a. It is an atom.
 - b. It is a molecule.
 - c. It is an ion.
 - d. It is a compound.
- _____ 23. How does a Ca^{2+} ion differ from a Ca^0 atom?
- a. Ca^{2+} ion has more electrons than Ca^0 atom.
 - b. Ca^{2+} ion has fewer electrons than Ca^0 atom.
 - c. Ca^{2+} ion has more protons than Ca^0 atom.
 - d. Ca^{2+} ion has fewer protons than Ca^0 atom.
- _____ 24. What is the correct chemical formula of the compound copper (II) oxide?
- a. CuO
 - b. Cu_2O
 - c. CuO_2
 - d. Cu_2O_2
- _____ 25. What is the formula for the ionic compound that contains Fe^{3+} ion and Cl^{2-} ion?
- a. FeCl_2
 - b. FeCl
 - c. Fe_3Cl_2
 - d. Fe_2Cl_3
- _____ 26. What does a chemical equation represent?
- a. It describes a chemical reaction.
 - b. It illustrates nuclear and biological reactions.
 - c. It guides the naming of chemical compounds given their chemical formulae.
 - d. It shows how to write chemical formulae given the name of the chemical compounds.

_____ 27. Which of the following chemical equations represents the word equation “potassium reacts with magnesium chloride to form potassium chloride and magnesium?”

- a. $\text{K} + \text{Mg} + \text{Cl} \longrightarrow \text{KCl} + \text{Mg}$
- b. $\text{K} + \text{MgCl}_2 \longrightarrow \text{KCl} + \text{Mg}$
- c. $\text{KCl} + \text{Mg} \longrightarrow \text{K} + \text{MgCl}_2$
- d. $\text{KCl} \longrightarrow \text{K} + \text{Cl} + \text{Mg}$

_____ 28. What is the relationship between the total mass of the reactants and the total mass of the products in a chemical reaction?

- a. The total mass of the reactants and that of the products are equal.
- b. The total mass of the reactants should be greater.
- c. The total mass of the product should be greater.
- d. There is no relationship between them.

_____ 29. Which of the following chemical equations does not demonstrate the law of conservation of mass?

- a. $2 \text{Mg} + \text{O}_2 \longrightarrow 2 \text{MgO}$
- b. $2 \text{H}_2\text{O}_2 \longrightarrow 2 \text{H}_2\text{O} + \text{O}_2$
- c. $\text{Mg} + \text{CuCl}_2 \longrightarrow \text{Cu} + \text{MgCl}_2$
- d. $\text{Na}_2\text{S} + \text{HCl} \longrightarrow \text{H}_2\text{S} + 2 \text{NaCl}$

_____ 30. For the reaction: $\text{Al}_{(\text{s})} + \text{CuCl}_{2(\text{aq})} \longrightarrow \text{Cu}_{(\text{s})} + \text{AlCl}_{3(\text{aq})}$, what are the correct coefficients of Al, CuCl₂, Cu and AlCl₃?

a. 3, 2, 3, 2	c. 3, 2, 2, 3
b. 2, 3, 3, 2	d. 2, 3, 2, 3

- _____ 31. Which of the following is(are) a piece(s) of evidence that a chemical reaction occurred?
- a. formation of a solid
 - b. evolution of gas
 - c. change in colour
 - d. all of the above
- _____ 32. Which of the following metals is less reactive than copper?
- a. Iron
 - b. Potassium
 - c. Gold
 - d. Magnesium
- _____ 33. Given the reaction: $\text{Mg}_{(s)} + 2\text{HCl}_{(aq)} \longrightarrow \text{H}_{2(g)} + \text{MgCl}_{2(aq)}$. What type of reaction is this?
- a. Combination
 - b. Decomposition
 - c. Single Replacement
 - d. Double Displacement
- _____ 34. What would be the products of the reaction: $2\text{Na}_{(s)} + \text{CuO}_{(s)}$
- a. $\text{NaO}_{(s)} + \text{Cu}_{(s)}$
 - b. $\text{Na}_2\text{O}_{(s)} + \text{Cu}_{(s)}$
 - c. $\text{Na}_{(s)} + \text{CuO}_{(s)}$
 - d. $\text{Na}_{(s)} + \text{CuO}_{(s)}$
- _____ 35. During a single replacement reaction, when could a single metal replace another metal in an ionic compound?
- a. The metal could replace another metal if it can lose electrons more readily than the other metal.
 - b. The metal could replace another metal if it can gain electrons more readily than the other metal.
 - c. Both a and b
 - d. No this is not possible.

- _____ 36. The reaction between iron metal and oxygen gas is classified as what type of chemical reaction?
- a. Combination
 - b. Decomposition
 - c. Single Replacement
 - d. Double Displacement
- _____ 37. Which of the following is TRUE about combination reactions?
- a. It always involves the reaction between an element and an ionic compound.
 - b. It always needs oxygen gas as one of the reactants.
 - c. It uses a single reactant.
 - d. It forms only one product.
- _____ 38. Which of the following reactions is a decomposition type of reaction?
- a. $2\text{Mg}_{(s)} + \text{O}_{2(g)} \longrightarrow 2\text{MgO}_{(s)}$
 - b. $\text{CaO}_{(s)} + \text{H}_2\text{O}_{(l)} \longrightarrow \text{Ca}(\text{OH})_{2(s)}$
 - c. $\text{CH}_{4(g)} + 2\text{O}_{2(g)} \longrightarrow \text{CO}_{2(g)} + 2\text{H}_2\text{O}_{(l)}$
 - d. $2\text{H}_2\text{O}_{2(l)} \longrightarrow 2\text{H}_2\text{O}_{(l)} + \text{O}_{2(g)}$
- _____ 39. Which of the following BEST describes a catalyst?
- a. It is a reactant in a chemical reaction.
 - b. It is a product in a chemical reaction.
 - c. It is a substance that increases the energy of the products in a chemical reaction.
 - d. It is a substance that speeds up a chemical reaction without being consumed in the reaction.
- _____ 40. The reaction: $\text{Ca}(\text{OH})_{2(aq)} + \text{HCl}_{(aq)} \longrightarrow \text{CaCl}_{2(s)} + 2\text{H}_2\text{O}_{(l)}$ is classified as which type of chemical reaction?
- a. Combination
 - b. Decomposition
 - c. Single Replacement
 - d. Double Displacement

Appendix B.2 Answer Key – Prior Knowledge Test

1. D	21. C
2. A	22. D
3. B	23. B
4. A	24. A
5. C	25. D
6. B	26. A
7. B	27. B
8. B	28. A
9. A	29. D
10. B	30. B
11. B	31. D
12. D	32. C
13. B	33. C
14. B	34. B
15. A	35. A
16. C	36. A
17. C	37. D
18. B	38. D
19. C	39. D
20. B	40. D

Appendix B.3 Table of Specifications – Prior Knowledge Test

Topic	Cognitive Domains TIMSS 2015 Science Framework (Jones et al., 2015)			No. of items	% of the test
	Knowing	Applying	Reasoning		
<i>Classification of Matter</i>					
1. Describe what is an aqueous solution and its properties (JHS)		Item #2		1	2.5%
2. Differentiate between elements and compounds (JHS and SHS)		#3 and #4		2	5%
3. Differentiate between metals and non-metals (JHS)		#5	#6	2	5%
<i>Atomic Structure</i>					
4. Describe what are protons, neutrons and electrons, and their location in the atom (JHS)	#7	#8		2	5%
5. Determine the number of protons, neutrons, and electrons in a particular atom (JHS)		#9 and #10		2	5%
6. Explain how the Quantum Mechanical Model of the atom describes the energies and positions of the electrons (JHS)	#11	#12		2	5%
<i>Chemical Bonding</i>					
7. Explain the formation of ionic and metallic bonds (JHS)	#13	#14, #15, #16 and #17	#18	6	15%
8. Explain how ions are formed (JHS)		#19 and #20	#21	3	7.5%
9. Differentiate among atoms, molecules, ions and give examples (SHS)		#22	#23	2	5%
10. Represent compounds using chemical formulae, structural formulae, and models (SHS)		#24 and #25		2	5%

<i>Chemical Reactions</i>					
11. Write equations for chemical reactions (including symbols) and balance the equations (SHS)	#1	26, #27 and #39		4	10%
12. Interpret the meaning of a balanced chemical reaction in terms of the law of conservation of mass (JHS and SHS)		#28 and #30	#29	3	7.5%
13. Describe pieces of evidence that a chemical reaction has occurred (SHS)	#31			1	2.5%
14. Use the idea of the reactivity series to explain replacement reaction and predict its product (added)		#32 and #33	#34 and #35	4	10%
15. Recognize the four types of chemical reaction (added)			#36, #37, #38 and #40	4	10%
No. of items	5	24	11	40	100%

* JHS – Junior High School

* SHS – Senior High School

Appendix C.1 Practice Worksheet I (Teacher-Feedback Group)

Name: _____

Grade and section: _____ Date: _____ Score: _____

Age: _____ Gender: _____ Team No. _____

Activity

Extraction of iron

Objective:

1. To demonstrate how iron could be extracted using carbon.

Materials:

- ❖ For each team:
 - A test tube
 - Iron ring and clamp
 - Bunsen burner
 - 2 spatulas
 - Iron (III) oxide
 - Activated carbon
 - Magnet
 - Colouring materials
- ❖ For the class: a container for disposal of waste chemicals

Safety precautions:

- Do not play with the Bunsen burner.
- Avoid inhaling, ingesting, eye contact and skin contact with the chemicals. Wear proper laboratory attire including safety goggles, gloves, and mask to protect your eyes, hands and breathing.
- Have a well-ventilated working place.

- During disposal, all waste chemicals shall be put in a separate disposal container.
Do not throw them into the sink and do not release them into the environment.
- Wash your hands thoroughly after working.

Procedure and macroscopic observations:

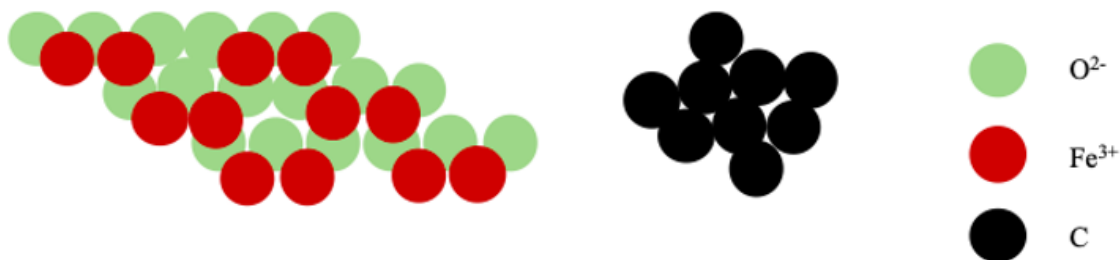
- Place a small amount of iron (III) oxide in a test tube.
- Bring a magnet bar close to it. Is the iron (III) oxide attracted to the magnet?

- Add a small amount of activated carbon.
- Bring again the magnet bar close to the mixture. Is the mixture attracted to the magnet?

- Prepare a heating set-up using the iron stand, iron clamp and Bunsen burner. Then, heat the iron (III) oxide-carbon mixture.
- If you see any colour change, stop heating the mixture. Then, allow it to cool for few minutes.
- Once cooled, bring the magnet bar close to the resulting mixture. Is the resulting mixture attracted to the magnet? _____

Integrating submicroscopic and symbolic representations:

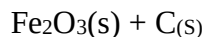
- This particulate diagram is a submicroscopic representation of the reactants in the chemical reaction [iron (III) oxide and carbon] you have just performed and observed.



2. a. In words, we could say that:

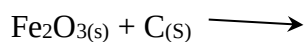
Solid iron (III) oxide reacts with solid carbon

- b. In symbols, we could write:



- a. Predict what will be the product(s) of this reaction. Using your pen and colouring materials, sketch your prediction on the provided space below.
- b. Do not forget to add specific and detailed labels to your sketches, e.g., when referring to particles be specific whether you are referring to atoms, ions, molecules, electrons, protons, or charges.
- c. Write a detailed description or explanation of your sketch.

3. Now, write the complete (reactants and products) and balanced chemical equation of this chemical reaction. Remember to use the smallest whole number ratio for your coefficients.



- On giving feedback: Refer to the following instruction when giving feedback to the students.

A. The rubric for evaluating the sketches is given below. Refer to this when evaluating the students' sketches.

Rubric for Evaluating Sketches			
Criteria	Description		
	<i>Excellent</i>	<i>Good</i>	<i>Poor</i>
The sketch's representations of the criteria are...			
a. Identity of the chemical species involved in the reaction (e.g., atoms, ions, molecules, electrons, protons, and charges)		not so clear, have minor errors and some details are missing	difficult to understand, have major errors and many important details are missing
b. Conservation of atoms, before and after the reaction	clear, accurate and complete		
c. Arrangement of the chemical species based on the phases of the substances			
d. Distance among particles based on the phases of the substances			

B. When giving feedback to the students based on the rubric, consider the following delivery *moves*: adding detail, removing an idea, revising an idea, and finding out more about an idea. Decide which of the four delivery *moves* (or probably all of them) are applicable to help the students improve their sketches. Do not forget to justify the appropriateness of your comments. Below are prompts to help you deliver your feedback.

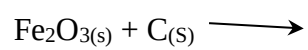
- Adding a detail: I think you need to add ...because ...This is based on...
- Removing an idea: I think you need to remove ... because ... This is based on ...
- Revising an idea: I think you need to revise ... because ... This is based on ...
- Finding out more about an idea: I think you might want to explain more about ... because ... This is based on ...

Revisions:

- [illegible]

3. Finally, write the complete and balanced chemical equation of the chemical reaction.

Remember to use the smallest whole number ratio for your coefficients.



Appendix C.2 Practice Worksheet II (Peer-Feedback Group)

Name: _____

Grade and section: _____ Date: _____ Score: _____

Age: _____ Gender: _____ Team No. _____

Activity

The reaction of ethanoic acid with water

Objective:

1. To demonstrate the reaction of ethanoic acid (a weak acid) with water.

Materials:

❖ For each team:

- 2 beakers
- 2 graduated cylinders
- Ethanoic acid (commonly known as acetic acid)
- Distilled water
- Phenolphthalein
- Colouring materials

❖ For the class: a container for disposal of waste chemicals

Safety precautions:

- Avoid inhaling, ingesting, eye contact and skin contact with the ethanoic acid.
Wear proper laboratory attire including safety goggles, gloves, and mask to protect your eyes, hands and breathing.
- Have a well-ventilated working place.
- **Remember to add the acid into the water and not the reverse!**
- During disposal, all waste acids shall be put in a separate disposal container. Do not pour them into the sink and do not release them into the environment.

- Wash your hands thoroughly after working.

Procedure and macroscopic observations:

1. Measure 20 mL each of the ethanoic acid and distilled water.
2. Put the ethanoic acid and distilled water into two separate beakers.
3. In the beaker containing distilled water, add 1-2 drops of phenolphthalein (indicator).
4. Pour the beaker containing ethanoic acid into the beaker containing distilled water.

Remember to add the acid into the water and not the reverse!

5. What happened? _____

Integrating submicroscopic and symbolic representations:

1. This particulate diagram is a submicroscopic representation of the reactants in the chemical reaction [ethanoic acid and water] you have just performed and observed.

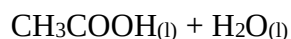


(Upon further review, it was recognised that there were errors in the diagram, i.e., representing hydrogen and oxygen as ions. Nevertheless, the teacher correctly identified water as a molecule in his feedback)

2. a. In words, we could say that:

liquid ethanoic acid reacts with liquid water

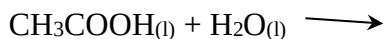
- b. In symbols, we could write:



3. a. Predict what will be the product(s) of this dissociation reaction. Using your pen and coloured pencils, sketch your prediction on the provided space.

- b. Do not forget to add specific and detailed labels to your sketches, e.g., when referring to particles be specific whether you are referring to atoms, ions, molecules, electrons, protons, or charges.
- c. Write a detailed description or explanation of your sketch.

4. Now, write the complete (reactants and products) and balanced chemical equation of this dissociation reaction. Remember to use the smallest whole number ratio for your coefficients.



- On giving feedback: Refer to the following instruction when giving feedback to your classmates.

A. The rubric for evaluating the sketches is given below. Refer to this when evaluating your classmates' sketches.

Rubric for Evaluating Sketches			
Criteria	Description		
	<i>Excellent</i>	<i>Good</i>	<i>Poor</i>
The sketch's representations of the criteria are...			
a. Identity of the chemical species involved in the reaction (e.g., atoms, ions, molecules, electrons, protons, and charges)	clear, accurate and complete	not so clear, have minor errors and some details are missing	difficult to understand, have major errors and many important details are missing
b. Conservation of atoms, before and after the reaction			
c. Arrangement of the chemical species based on the phases of the substances			
d. Distance among particles based on the phases of the substances			

B. When giving feedback to your classmates based on the rubric, consider the following delivery *moves*: adding detail, removing an idea, revising an idea, and finding out more about an idea. Decide which of the four delivery *moves* (or probably all of them) are applicable to help your classmates improve their sketches. Do not forget to justify the appropriateness of your comments. Below are prompts to help you deliver your feedback.

- a. Adding a detail: I think you need to add ...because ...This is based on...

- b. Removing an idea: I think you need to remove ... because ... This is based on ...
- c. Revising an idea: I think you need to revise ... because ... This is based on ...
- d. Finding out more about an idea: I think you might want to explain more about ...
because ... This is based on ...

Revisions:

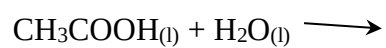
1. After receiving feedback from your classmates, which of those comments you think are relevant for you and you will adopt to improve your sketch? Write them all down here.

2. Revising your sketch:

- a. Based on the feedback you received, sketch again your prediction of the products formed by the dissociation of ethanoic acid in water. Use the space provided below.

- b. Do not forget to add specific and detailed labels to your sketches, e.g., when referring to particles be specific whether you are referring to atoms, ions, molecules, electrons, protons, or charges.
- c. Write a detailed description or explanation of your sketch.

3. Finally, write the complete and balanced chemical equation of the dissociation reaction. Remember to use the smallest whole number ratio for your coefficients.



Appendix D.1 Worksheet 1 (Teacher-Feedback Group)

Name: _____

Grade and section: _____ Date: _____ Score: _____

Age: _____ Gender: _____ Team No. _____

Activity**Combination/synthesis reaction****Objective:**

1. To illustrate combination/synthesis reaction as a type of chemical reaction.

Materials:

- ❖ For each team:
 - A piece of about 5-cm long magnesium
 - Crucible tong
 - Bunsen burner or alcohol lamp
- ❖ For the class: a container for disposal of chemical waste

Safety precautions:

- Be very cautious in using the burner/lamp. Do not play with the flame.
- Do not look directly at the light emitted by the burning magnesium. It is very bright.
- When heating the magnesium, hold it away from your face or your classmates' faces.
- Avoid inhaling, ingesting, eye contact and skin contact with magnesium and the fumes released when burning it. Wear proper laboratory attire including safety goggles, gloves, and mask to protect your eyes, hands and breathing.
- Have a well-ventilated working place.

- During disposal, all the waste magnesium strips shall be put in a separate disposal container. Do not throw them into the sink and do not release them into the environment.
- Wash your hands thoroughly after working.

Procedure:

1. Look at the piece of magnesium metal. Take note of its physical characteristics. List them all down here.
2. Using a crucible tong, hold the strip of magnesium and heat it with the Bunsen burner/alcohol lamp.
3. Observe what happened to the strip of magnesium during and after it was burned. Write your observation here.

Before the reaction (Describe the reactant/s)	After the reaction (Describe the product/s formed)

- On giving feedback (teacher-feedback): Refer to the following instruction when giving feedback to your students.

A. The rubric for evaluating the sketches is given below. Refer to this when evaluating your students' sketches.

Rubric for Evaluating Sketches			
Criteria	Description		
	<i>Excellent</i>	<i>Good</i>	<i>Poor</i>
The sketch's representations of the criteria are...			
a. Identity of the chemical species involved in the reaction (e.g., atoms, ions, molecules, electrons, protons, and charges)		not so clear, have minor errors and some details are missing	difficult to understand, have major errors and many important details are missing
b. Conservation of atoms, before and after the reaction	clear, accurate and complete		
c. Arrangement of the chemical species based on the phases of the substances			
d. Distance among particles based on the phases of the substances			

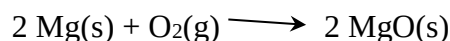
B. When giving feedback to the students based on the rubric, consider the following delivery *moves*: adding detail, removing an idea, revising an idea, and finding out more about an idea. Decide which of the four delivery *moves* (or probably all of them) are applicable to help the students improve their sketches. Do not forget to justify the appropriateness of your comments. Below are prompts to help you deliver your feedback.

- Adding a detail: I think you need to add ...because ...This is based on...
- Removing an idea: I think you need to remove ... because ... This is based on ...
- Revising an idea: I think you need to revise ... because ... This is based on ...
- Finding out more about an idea: I think you might want to explain more about ... because ... This is based on ...

3. After receiving feedback from your teacher, which of those comments you think are relevant for you and you will adopt to improve your sketch? Write them all down here.

4. Revising your sketch:

- a. Based on the comments you received, sketch again what you think occurred in this chemical reaction at the submicroscopic level? Sketch what occurs before the reaction (describe the reactant/s) and after the reaction (describe the product/s formed) at the submicroscopic level.
- b. The chemical equation of the reaction of burning magnesium is again presented for your reference:



- c. Use the same table to guide you. If space is not enough, you may use a new sheet of paper.
- d. Do not forget to add specific and detailed labels to your sketches, e.g., when referring to particles be specific whether you are referring to atoms, ions, molecules, electrons, protons, or charges.
- e. Write a detailed description of your sketch using the lines at the bottom of the table.

Before the reaction (Describe the reactant/s)	After the reaction (Describe the product/s formed)

[illegible]

Appendix D.2 Worksheet 2 (Peer-Feedback Group)

Name: _____

Grade and section: _____ Date: _____ Score: _____

Age: _____ Gender: _____ Team No. _____

Activity**Decomposition reaction****Objective:**

1. To illustrate decomposition reaction as a type of chemical reaction.

Materials:

- ❖ For each team:
 - 5-mL hydrogen peroxide solution (35% w/v)
 - Small beaker
 - Match head size of manganese (IV) oxide/manganese dioxide (catalyst)
 - Glowing wooden splint
- ❖ For the class: a container for disposal of chemical waste

Safety precautions:

- Avoid inhaling, ingesting, eye contact and skin contact with the chemicals.
Hydrogen peroxide is both an irritant and corrosive. Manganese (IV) oxide and oxygen gas are irritants too.
- Wear proper laboratory attire including safety goggles, gloves, and mask to protect your eyes, hands and breathing, respectively.
- Have a well-ventilated working place.
- Do not bring combustible materials near the manganese (IV) oxide/hydrogen peroxide mixture.

- During disposal, pour the hydrogen peroxide reaction mixture in a waste container labelled "Manganese (IV) oxide/Hydrogen peroxide mixture". Do not pour it into the sink and do not release it into the environment.
- Wash your hands thoroughly after working.

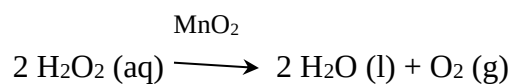
Procedure:

1. Put 5 mL of hydrogen peroxide solution into the beaker. Take note of its physical characteristics. List them all down here.
2. Add a match head size of the catalyst [manganese (IV) oxide] into the beaker containing hydrogen peroxide solution. What did you observe?

Guide questions:

1. What pieces of evidence of chemical reaction did you observe?

2. This chemical reaction of the decomposition of hydrogen peroxide is represented by the chemical equation:



- a. Using the given chemical equation as a guide, what do you think occurred in this chemical reaction at the submicroscopic level? Sketch what occurs before the reaction (describe the reactant/s) and after the reaction (describe the product/s formed) at the submicroscopic level.
- b. Use the table on the next page to guide you. If space is not enough, you may use a new sheet of paper.
- c. Do not forget to add specific and detailed labels to your sketches, e.g., when referring to particles be specific whether you are referring to atoms, ions, molecules, electrons, protons, or charges.
- d. Write a detailed description of your sketch using the lines at the bottom of the table.

Before the reaction (Describe the reactant/s)	After the reaction (Describe the product/s formed)

[illegible]

- On giving feedback: Refer to the following instruction when giving feedback to your classmates.

A. The rubric for evaluating the sketches is given below. Refer to this when evaluating your classmates' sketches.

Rubric for Evaluating Sketches			
Criteria	Description		
	<i>Excellent</i>	<i>Good</i>	<i>Poor</i>
The sketch's representations of the criteria are...			
a. Identity of the chemical species involved in the reaction (e.g., atoms, ions, molecules, electrons, protons, and charges)		not so clear, have minor errors and some details are missing	difficult to understand, have major errors and many important details are missing
b. Conservation of atoms, before and after the reaction	clear, accurate and complete		
c. Arrangement of the chemical species based on the phases of the substances			
d. Distance among particles based on the phases of the substances			

B. When giving feedback to your classmates based on the rubric, consider the following delivery *moves*: adding detail, removing an idea, revising an idea, and finding out more about an idea. Decide which of the four delivery *moves* (or probably all of them) are applicable to help your classmates improve their sketches. Do not forget to justify the appropriateness of your comments. Below are prompts to help you deliver your feedback.

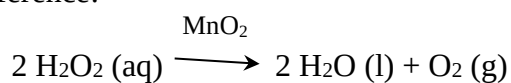
- Adding a detail: I think you need to add ...because ...This is based on...
- Removing an idea: I think you need to remove ... because ... This is based on ...
- Revising an idea: I think you need to revise ... because ... This is based on ...
- Finding out more about an idea: I think you might want to explain more about ... because ... This is based on ...

3. After receiving feedback from your classmates, which of those comments you think are relevant for you and you will adopt to improve your sketch? Write them all down here.

4. Revising your sketch:

- a. Based on the comments you received, sketch again what you think occurred in this chemical reaction at the submicroscopic level? Sketch what occurs before the reaction (describe the reactant/s) and after the reaction (describe the product/s formed) at the submicroscopic level.

- b. The chemical equation of the decomposition of hydrogen peroxide is again presented for your reference:



- c. Use the same table to guide you. If space is not enough, you may use a new sheet of paper.
- d. Do not forget to add specific and detailed labels to your sketches, e.g., when referring to particles be specific whether you are referring to atoms, ions, molecules, electrons, protons, or charges.
- e. Write a detailed description of your sketch using the lines at the bottom of the table.

Before the reaction (Describe the reactant/s)	After the reaction (Describe the product/s formed)

[illegible]

Appendix D.3 Worksheet 3 (Teacher-Feedback Group)

Name: _____

Grade and section: _____ Date: _____ Score: _____

Age: _____ Gender: _____ Team No. _____

Activity**Replacement reaction of metal in solution****Objective:**

1. To illustrate a single replacement reaction as a type of chemical reaction in an aqueous solution.

Materials:

- ❖ For each team:
 - A piece of about 1-cm long magnesium
 - 0.1 M copper (II) chloride solution
 - Test tube
 - Test tube rack
 - Forceps
- ❖ For the class: a container for disposal of chemical waste

Safety precautions:

- Keep magnesium away from the flame.
- Avoid inhaling, ingesting, eye contact and skin contact with all the chemicals. Wear proper laboratory attire including safety goggles and gloves to protect your eyes and hands.
- Copper (II) chloride is toxic!

- During disposal, the magnesium/copper (II) chloride mixture shall be put in a container. Do not pour them into the sink and do not release them into the environment.
- Wash thoroughly after working.

Procedure:

1. Look at the piece of magnesium metal. Take note of its physical characteristics. List them all down here.
2. Pour about 10 mL of copper (II) chloride solution into a test tube. Then, using the pair of forceps place the piece of magnesium metal into the test tube of copper (II) chloride solution.
3. Observe for about five minutes. What do you see? List them all down here.

Guide questions:

1. What pieces of evidence of chemical change did you observe?

2. This chemical reaction between magnesium and copper (II) chloride is represented by the chemical equation:



- a. Using the given chemical equation as a guide, what do you think occurred in this chemical reaction at the submicroscopic level? Sketch what occurs before the reaction (describe the reactant/s) and after the reaction (describe the product/s formed) at the submicroscopic level.
- b. Use the table on the next page to guide you. If space is not enough, you may use a new sheet of paper.
- c. Do not forget to add specific and detailed labels to your sketches, e.g., when referring to particles be specific whether you are referring to atoms, ions, molecules, electrons, protons, or charges.
- d. Write a detailed description of your sketch using the lines at the bottom of the table.

Before the reaction (Describe the reactant/s)	After the reaction (Describe the product/s formed)

- On giving feedback (teacher-feedback): Refer to the following instruction when giving feedback to your students.

A. The rubric for evaluating the sketches is given below. Refer to this when evaluating your students' sketches.

Rubric for Evaluating Sketches			
Criteria	Description		
	<i>Excellent</i>	<i>Good</i>	<i>Poor</i>
The sketch's representations of the criteria are...			
a. Identity of the chemical species involved in the reaction (e.g., atoms, ions, molecules, electrons, protons, and charges)		not so clear, have minor errors and some details are missing	difficult to understand, have major errors and many important details are missing
b. Conservation of atoms, before and after the reaction	clear, accurate and complete		
c. Arrangement of the chemical species based on the phases of the substances			
d. Distance among particles based on the phases of the substances			

B. When giving feedback to the students based on the rubric, consider the following delivery *moves*: adding detail, removing an idea, revising an idea, and finding out more about an idea. Decide which of the four delivery *moves* (or probably all of them) are applicable to help the students improve their sketches. Do not forget to justify the appropriateness of your comments. Below are prompts to help you deliver your feedback.

- Adding a detail: I think you need to add ...because ...This is based on...
- Removing an idea: I think you need to remove ... because ... This is based on ...
- Revising an idea: I think you need to revise ... because ... This is based on ...
- Finding out more about an idea: I think you might want to explain more about ... because ... This is based on ...

3. After receiving feedback from your teacher, which of those comments you think are relevant for you and you will adopt to improve your sketch? Write them all down here.

4. Revising your sketch:

- a. Based on the comments you received, sketch again what you think occurred in this chemical reaction at the submicroscopic level? Sketch what occurs before the reaction (describe the reactant/s) and after the reaction (describe the product/s formed) at the submicroscopic level.
- b. The chemical equation of the reaction between magnesium and copper (II) chloride is again presented for your reference:



- c. Use the same table to guide you. If space is not enough, you may use a new sheet of paper.
- d. Do not forget to add specific and detailed labels to your sketches, e.g., when referring to particles be specific whether you are referring to atoms, ions, molecules, electrons, protons, or charges.
- e. Write a detailed description of your sketch using the lines at the bottom of the table.

Before the reaction (Describe the reactant/s)	After the reaction (Describe the product/s formed)

Appendix D.4 Worksheet 4 (Peer-Feedback Group)

Name: _____

Grade and section: _____ Date: _____ Score: _____

Age: _____ Gender: _____ Team No. _____

Activity

Double displacement reaction

Objective:

1. To illustrate double displacement reaction, a type of chemical reaction.

Materials:

- ❖ For each team:
 - 1 gram of sodium sulfide
 - 5 mL of hydrochloric acid
 - Test tube
 - Pipette
 - Lead acetate paper strip (to test the product/s formed)
- ❖ For the class: 2 containers for disposal of chemical wastes

Safety precautions:

- Avoid inhaling, ingesting, eye contact and skin contact with the chemicals. Sodium sulfide is an irritant. Hydrochloric acid is corrosive.
- Do not inhale the sodium sulfide/hydrochloric acid mixture. Also, keep away flame from this mixture.
- Wear proper laboratory attire including safety goggles, masks, and gloves to protect your eyes, breathing and hands.
- Have a well-ventilated working place.

- During disposal, all waste mixtures and paper strips shall be put in separate disposal containers. Do not pour or throw them into the sink and do not release them into the environment.
- Wash your hands thoroughly after working.

Procedure:

1. Look at sodium sulfide and hydrochloric acid. Take note of their physical characteristics. List them all down here.
2. Put the sodium sulfide into the test tube. Then, add the hydrochloric acid into it using the pipette.
3. Bring in a lead acetate paper strip inside the test tube, just on top of the sodium sulfide/hydrochloric acid mixture.
4. Observe what happens.
 - a. What happened to the lead acetate paper strip? What does it tell you?
 - b. What happened to the sodium sulfide/hydrochloric acid mixture?

Guide questions:

1. What pieces of evidence of chemical change did you observe?

2. This chemical reaction between sodium sulfide and hydrochloric acid is represented by the chemical equation:



- a. Using the given chemical equation as a guide, what do you think occurred in this chemical reaction at the submicroscopic level? Sketch what occurs before the reaction (describe the reactant/s) and after the reaction (describe the product/s formed) at the submicroscopic level.
- b. Use the table on the next page to guide you. If space is not enough, you may use a new sheet of paper.
- c. Do not forget to add specific and detailed labels to your sketches, e.g., when referring to particles be specific whether you are referring to atoms, ions, molecules, electrons, protons, or charges.
- d. Write a detailed description of your sketch using the lines at the bottom of the table.

Before the reaction (Describe the reactant/s)	After the reaction (Describe the product/s formed)

[illegible]

- On giving feedback: Refer to the following instruction when giving feedback to your classmates.

A. The rubric for evaluating the sketches is given below. Refer to this when evaluating your classmates' sketches.

Rubric for Evaluating Sketches			
Criteria	Description		
	<i>Excellent</i>	<i>Good</i>	<i>Poor</i>
The sketch's representations of the criteria are...			
a. Identity of the chemical species involved in the reaction (e.g., atoms, ions, molecules, electrons, protons, and charges)		not so clear, have minor errors and some details are missing	difficult to understand, have major errors and many important details are missing
b. Conservation of atoms, before and after the reaction	clear, accurate and complete		
c. Arrangement of the chemical species based on the phases of the substances			
d. Distance among particles based on the phases of the substances			

B. When giving feedback to your classmates based on the rubric, consider the following delivery *moves*: adding detail, removing an idea, revising an idea, and finding out more about an idea. Decide which of the four delivery *moves* (or probably all of them) are applicable to help your classmates improve their sketches. Do not forget to justify the appropriateness of your comments. Below are prompts to help you deliver your feedback.

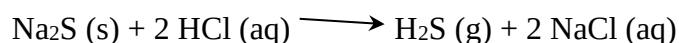
- Adding a detail: I think you need to add ...because ...This is based on...
- Removing an idea: I think you need to remove ... because ... This is based on ...
- Revising an idea: I think you need to revise ... because ... This is based on ...
- Finding out more about an idea: I think you might want to explain more about ... because ... This is based on ...

3. After receiving feedback from your classmates, which of those comments you think are relevant for you and you will adopt to improve your sketch? Write them all down here.

4. Revising your sketch:

- a. Based on the comments you received, sketch again what you think occurred in this chemical reaction at the submicroscopic level? Sketch what occurs before the reaction (describe the reactant/s) and after the reaction (describe the product/s formed) at the submicroscopic level.

- b. The chemical equation of the reaction between sodium sulfide and hydrochloric acid is again presented for your reference:



- c. Use the same table to guide you. If space is not enough, you may use a new sheet of paper.
- d. Do not forget to add specific and detailed labels to your sketches, e.g., when referring to particles be specific whether you are referring to atoms, ions, molecules, electrons, protons, or charges.
- e. Write a detailed description of your sketch using the lines at the bottom of the table.

Before the reaction (Describe the reactant/s)	After the reaction (Describe the product/s formed)

Appendix E Recall Test

Name: _____

Grade and section: _____ Date: _____ Score: _____

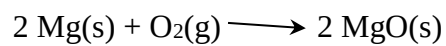
Age: _____ Gender: _____ Team No. _____

A. Please answer as completely as possible.

1. Recall the four chemical reactions you studied in class:
 - a. burning of magnesium
 - b. decomposition of hydrogen peroxide [with manganese (IV) oxide as catalyst]
 - c. sodium sulfide and hydrochloric acid
 - d. magnesium metal and copper (II) chloride solution
2. Sketch everything that you could remember about what occurs before each reaction (describe the reactant/s) and after each reaction (describe the product/s formed) at the submicroscopic level.
3. Use the same table (from the worksheets) to guide you. If space is not enough, you may use a new sheet of paper.
4. Do not forget to add specific and detailed labels to your sketches, e.g., when referring to particles be specific whether you are referring to atoms, ions, molecules, electrons, protons, or charges.
5. Write a detailed description of your sketch using the lines at the bottom of each table.
6. You could put your answers on the next pages.

B. Your sketches here.

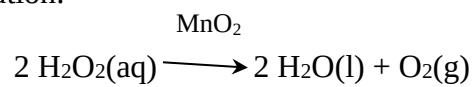
1. The chemical reaction of burning magnesium is represented by the chemical equation:



Before the reaction (Describe the reactant/s)	After the reaction (Describe the product/s formed)

[illegible]

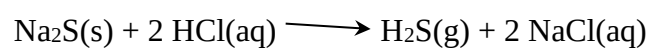
2. The chemical reaction of the decomposition of hydrogen peroxide is represented by the chemical equation:



Before the reaction (Describe the reactant/s)	After the reaction (Describe the product/s formed)

[illegible]

3. The chemical reaction between sodium sulfide and hydrochloric acid is represented by the chemical equation:



Before the reaction (Describe the reactant/s)	After the reaction (Describe the product/s formed)

[illegible]

4. The chemical reaction between magnesium and copper (II) chloride is represented by the chemical equation:



Before the reaction (Describe the reactant/s)	After the reaction (Describe the product/s formed)

Appendix F Transfer Test

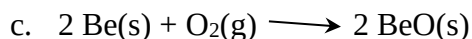
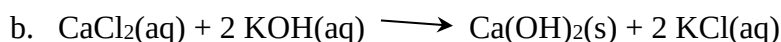
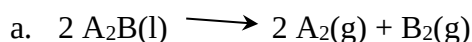
Name: _____

Grade and section: _____ Date: _____ Score: _____

Age: _____ Gender: _____ Team No. _____

A. Please answer as completely as possible.

1. If you can see what is happening to these chemical reactions at the submicroscopic level, what would you see? Sketch what occurs before each reaction (describe the reactant/s) and after each reaction (describe the product/s formed) at the submicroscopic level.

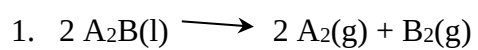


- d. What will be the product(s) of this reaction? Write the complete and balanced chemical equation and sketch the complete reaction.



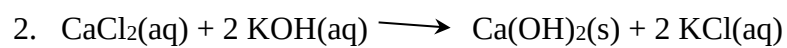
2. Use the same table (from the worksheets) to guide you. If space is not enough, you may use a new sheet of paper.
3. Do not forget to add specific and detailed labels to your sketches, e.g., when referring to particles be specific whether you are referring to atoms, ions, molecules, electrons, protons, or charges.
4. Write a detailed description of your sketch using the lines at the bottom of each table.
5. You could put your answers on the next pages.

B. Your sketches here.



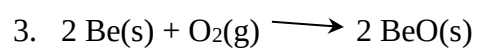
Before the reaction (Describe the reactant/s)	After the reaction (Describe the product/s formed)

[illegible]



Before the reaction (Describe the reactant/s)	After the reaction (Describe the product/s formed)

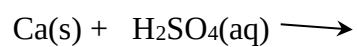
[illegible]



Before the reaction (Describe the reactant/s)	After the reaction (Describe the product/s formed)

[illegible]

4. What will be the product(s) of this reaction? Write the complete and balanced chemical equation and sketch the complete reaction.



Before the reaction (Describe the reactant/s)	After the reaction (Describe the product/s formed)

[illegible]

Appendix G Teacher's Guide

Overview:

The teaching-learning strategy (sketching coupled with feedback) that you are about to implement covers six sessions. These sessions are about stoichiometry (sessions 1 and 2) and the types of chemical reactions (sessions 4 to 6).

Session 1: Extraction of iron

Session 2: Reaction of ethanoic acid and water

Session 3: Combination/synthesis reaction

Session 4: Decomposition reaction

Session 5: Replacement reaction of metal in solution

Session 6: Double displacement reaction

The overall objective of these sessions is to cultivate students' submicroscopic understanding of chemical reactions using sketching coupled with feedback as a teaching-learning strategy.

For each session, your implementation shall be guided by a worksheet. Each worksheet has two versions: the teacher-feedback version and the peer-feedback version. Each of your two classes shall use one of the two versions, i.e., class A will use the teacher-feedback version and class B will use the peer-feedback version.

In both classes, you as their teacher is expected to facilitate the conduct of practical work about a chemical reaction. Students shall then be asked to sketch their submicroscopic understanding of this chemical reaction. After which, for class A (teacher-feedback) you are expected to give feedback to students' sketches using the prepared rubric and prompts. A copy of the feedback sheet is attached to this teacher's guide. For class B, after the conduct of the practical work and

sketching, you are expected to facilitate the students while giving feedback to their peers (you are not supposed to give feedback to them) using the same prepared rubric and prompts. After, receiving feedback from either you (their teacher) or their peers, students are expected to revise their sketches. At the end of the session, all worksheets shall be collected.

Moreover, video cameras shall be set up around the classroom to record the sessions. Before the first session, students' spatial ability and prior knowledge about chemical reactions shall be assessed. Then, immediately after and one month after the last session, their learning gains shall be assessed via recall and transfer tests.

A detailed discussion of the procedure on how to use each worksheet for each session is presented in the subsequent sections.

Session 1: Extraction of iron

Preparation:

1. Prepare all the laboratory apparatus and reagents needed before the class (one set for each team):
 - Test tube
 - Iron ring and clamp
 - Bunsen burner
 - 2 spatulas
 - Iron (III) oxide
 - Activated carbon
 - Magnet
 - Colouring materials
 - Disposal container for the whole class
2. Prepare the PowerPoint presentation of the particulate diagram, word equation and chemical equation of the chemical reaction to be studied.
3. Reproduce copies of the worksheet for each student.
4. Before the session, ask the students to bring coloured pencils or crayons, plus coloured markers and manila paper (for the teacher-feedback group).

Procedure:

Day 1

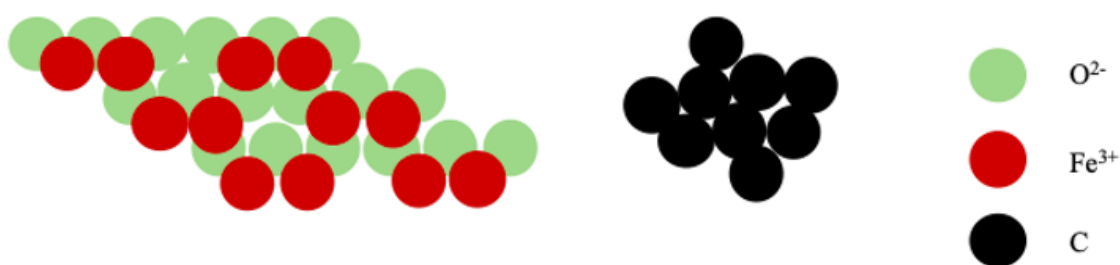
1. Pre-activity (15 minutes)
 - a. Students will be working in teams with six to seven members for each team.
 - b. Present to the students the objective, materials, safety precautions and procedure of the practical work on the reaction of iron (III) oxide and carbon (see the worksheet).

2. Activity proper (Practical work) (30 minutes)

- a. Let the students perform the practical work together as a team and take note of their macroscopic observations.

3. Post-activity (15 minutes)

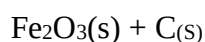
- a. After the students have performed the practical work and noted their macroscopic observations, show to the class this particulate diagram via PowerPoint presentation:



- b. Tell the students that this particulate diagram is a representation of the reactants, i.e., iron (III) oxide and carbon at the submicroscopic level.
- c. Tell the students that the red circles represent the Fe^{3+} ions bonded with O^{2-} ions represented by the green circles forming the solid ionic compound iron (III) oxide (two Fe^{3+} ions bonded with three O^{2-} ions). The black circles represent carbon atoms that are covalently bonded and make up the solid activated carbon.
- d. Then, show to the class via a PowerPoint slide that when put into word equation, this reaction could be presented as:

Solid iron (III) oxide reacts with solid carbon

In symbols, this reaction could be written as:



Sketching (30 minutes)

- e. Then, ask the students to predict what will be the product(s) of this reaction. Ask them to sketch these products on the worksheet individually using their pens and colouring materials. Asked them to add complete and detailed labels to their sketches and to be specific when they mention “particles”, i.e., are they referring to atoms, ions, molecules, electrons, protons, or charges. Finally, asked them to write a detailed description of their sketch.
- f. After sketching, ask the students to write the complete (reactants and products) and balanced chemical equation of the chemical reaction on the worksheet. Emphasize that they must use the smallest whole number ratio for their coefficients.

Day 2

Feedback (70-90 minutes)

Class A (Teacher-feedback)	Class B (Peer-feedback)
g. Ask each team to choose one representative who best represents the team's prediction of the products of the reaction (2 minutes).	g. Present the rubric and the prompts before the class. Tell them that these will be used by their peers to evaluate and improve their sketches. Tell them that these could be found in their worksheets (5 minutes).
h. Ask each team to copy the answers of the representative onto a manila paper to facilitate the whole-class presentation (8 minutes).	h. Let each student from each team present their sketch and their completed chemical equation to each other. Allow time for the presentation of each student
i. Present the rubric and the prompts before the class. Tell them, that these will be	

used by the teacher to evaluate and improve their sketches. Tell them that these could be found in their worksheets (5 minutes). j. Ask the representatives to present before the whole class their sketches and the complete chemical equation (16 minutes). k. Using the prepared rubric and the prompts, provide each sketch with feedback that students can use to improve their sketch (40 minutes). l. After all the teams have presented and received feedback from you (the teacher), ask each student to write all the comments from the teacher which they think are useful for them to improve their sketch. Let them write it on the worksheet (3 minutes). m. Let the students revise their sketches individually using the same materials (pens and colouring materials). Asked them to add complete and detailed labels to their sketches and to be specific when they mention “particles”, i.e., are they referring to atoms, ions, molecules,	(12-14 minutes) and for each peer to give feedback (30-35 minutes). i. After all the students have presented and received feedback from their peers, ask each student to write all the comments from the peers which they think are useful for them to improve their sketch. Let them write it on the worksheet (3 minutes). j. Let the students revise their sketches individually using the same materials (pens and colouring materials). Asked them to add complete and detailed labels to their sketches and to be specific when they mention "particles", i.e., are they referring to atoms, ions, molecules, electrons, protons, or charges. Finally, asked them to write a detailed description of their sketch. k. Finally, asked the students to write the complete and balanced chemical equation of the chemical reaction (15 minutes for j & k). l. Collect all the worksheets (1 minute).

electrons, protons, or charges. Finally, asked them to write a detailed description of their sketch. n. Finally, asked the students to write the complete and balanced chemical equation of the chemical reaction (15 minutes for m & n). o. Collect all the worksheets (1 minute).	

Session 2: Reaction of ethanoic acid and water

Preparation:

1. Prepare all the laboratory apparatus and reagents needed before the class (one set for each team):
 - 2 beakers
 - 2 graduated cylinders
 - Ethanoic acid (commonly known as acetic acid)
 - Distilled water
 - Phenolphthalein
 - Colouring materials
 - Disposal container for the whole class
2. Prepare the PowerPoint presentation of the particulate diagram, word equation and chemical equation of the chemical reaction to be studied.
3. Reproduce copies of the worksheet for each student.
4. Before the session, ask the students to bring coloured pencils or crayons, plus coloured markers and manila paper (for the teacher-feedback group).

Procedure:

Day 1

1. Pre-activity (15 minutes)
 - a. Students will be working in teams with six to seven members for each team.
 - b. Present to the students the objective, materials, safety precautions and procedure of the practical work on the reaction of ethanoic acid and water (see the worksheet).

2. Activity proper (Practical work) (30 minutes)

- a. Let the students perform the practical work together as a team and take note of their macroscopic observations.

3. Post-activity (15 minutes)

- a. After the students have performed the practical work and noted their macroscopic observations, show to the class this particulate diagram via PowerPoint presentation:



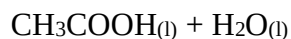
(Upon further review, it was recognised that there were errors in the diagram, i.e., representing hydrogen and oxygen as ions. Nevertheless, the teacher correctly identified water as a molecule in his feedback)

- b. Tell the students that this particulate diagram is a representation of the reactants, i.e., ethanoic acid and water at the submicroscopic level.
- c. Tell the students that the yellow circles represent acetate (CH_3COO) molecule bonded with hydrogen (H) atoms represented by the blue circles forming molecules of ethanoic acid (or acetic acid) in the liquid phase (as seen from the spaces between each molecule of the acid). The green circles represent oxygen (O) atoms that are covalently bonded with hydrogen (H) atoms forming water (H_2O) molecules in the liquid phase.

- d. Then, show to the class via a PowerPoint slide that when put into word equation, this reaction could be presented as:

liquid ethanoic acid reacts with liquid water

In symbols, this reaction could be written as:



Sketching (30 minutes)

- e. Then, ask the students to predict what will be the product(s) of this reaction. Ask them to sketch these products on the worksheet individually using their pens and colouring materials. Asked them to add complete and detailed labels to their sketches and to be specific when they mention “particles”, i.e., are they referring to atoms, ions, molecules, electrons, protons, or charges. Finally, asked them to write a detailed description of their sketch.
- f. After sketching, ask the students to write the complete (reactants and products) and balanced chemical equation of the chemical reaction on the worksheet. Emphasize that they must use the smallest whole number ratio for their coefficients.

Day 2

Feedback (70-90 minutes)

Class A (Teacher-feedback)	Class B (Peer-feedback)
g. Ask each team to choose one representative who best represents the team's prediction of the products of the reaction (2 minutes).	g. Present the rubric and the prompts before the class. Tell them that these will be used by their peers to evaluate and improve their sketches. Tell them that these could be found in their worksheets
h. Ask each team to copy the answers of the representative onto a manila paper to	(5 minutes).

facilitate the whole-class presentation (8 minutes). i. Present the rubric and the prompts before the class. Tell them, that these will be used by the teacher to evaluate and improve their sketches. Tell them that these could be found in their worksheets (5 minutes). j. Ask the representatives to present before the whole class their sketches and the complete chemical equation (16 minutes). k. Using the prepared rubric and the prompts, provide each sketch with feedback that students can use to improve their sketch (40 minutes). l. After all the teams have presented and received feedback from you (the teacher), ask each student to write all the comments from the teacher which they think are useful for them to improve their sketch. Let them write it on the worksheet (3 minutes). m. Let the students revise their sketches individually using the same materials	h. Let each student from each team present their sketch and their completed chemical equation to each other. Allow time for the presentation of each student (12-14 minutes) and for each peer to give feedback (30-35 minutes). i. After all the students have presented and received feedback from their peers, ask each student to write all the comments from the peers which they think are useful for them to improve their sketch. Let them write it on the worksheet (3 minutes). j. Let the students revise their sketches individually using the same materials (pens and colouring materials). Asked them to add complete and detailed labels to their sketches and to be specific when they mention "particles", i.e., are they referring to atoms, ions, molecules, electrons, protons, or charges. Finally, asked them to write a detailed description of their sketch. k. Finally, asked the students to write the complete and balanced chemical

(pens and colouring materials). Asked them to add complete and detailed labels to their sketches and to be specific when they mention “particles”, i.e., are they referring to atoms, ions, molecules, electrons, protons, or charges. Finally, asked them to write a detailed description of their sketch. n. Finally, asked the students to write the complete and balanced chemical equation of the chemical reaction (15 minutes for m & n). o. Collect all the worksheets (1 minute).	equation of the chemical reaction (15 minutes for j & k). l. Collect all the worksheets (1 minute).

Session 3: Combination/synthesis reaction

Preparation:

1. Prepare all the laboratory apparatus and reagents needed before the class (one set for each team):
 - A piece of about 5-cm long magnesium
 - Crucible tong
 - Bunsen burner or alcohol lamp
 - Colouring materials
 - Disposal container for the whole class
2. Reproduce copies of the worksheet for each student.
3. Before the session, ask the students to bring coloured pencils or crayons, plus coloured markers and manila paper (for the teacher-feedback group).

Procedure:

Day 1

1. Pre-activity (15 minutes)
 - a. Students will be working in teams with six to seven members for each team.
 - b. Present to the students the objective, materials, safety precautions and procedure of the practical work on the combustion of magnesium (see the worksheet).
2. Activity proper (Practical work) (30 minutes)
 - a. Let the students perform the practical work together as a team and take note of their macroscopic observations.
3. Post-activity

Sketching (45 minutes)

- a. After the conduct of the practical work, ask the students that if they can see what is happening to this reaction at the submicroscopic level, sketch what they could

see before and after the reaction. Let the students sketch individually using their pens and colouring materials and put their sketches on the worksheet guided by a before-and-after table. Asked them to add complete and detailed labels to their sketches and to be specific when they mention “particles”, i.e., are they referring to atoms, ions, molecules, electrons, protons, or charges. Finally, asked them to write a detailed description of their sketch.

Day 2

Feedback (70-90 minutes)

Class A (Teacher-feedback)	Class B (Peer-feedback)
b. Ask each team to choose one representative who best represents the team's prediction of the products of the reaction (2 minutes).	b. Present the rubric and the prompts before the class. Tell them that these will be used by their peers to evaluate and improve their sketches. Tell them that these could be found in their worksheets (5 minutes).
c. Ask each team to copy the answers of the representative onto a manila paper to facilitate the whole-class presentation (8 minutes).	c. Let each student from each team present their sketch and their completed chemical equation to each other. Allow time for the presentation of each student (12-14 minutes) and for each peer to give feedback (30-35 minutes).
d. Present the rubric and the prompts before the class. Tell them, that these will be used by the teacher to evaluate and improve their sketches. Tell them that these could be found in their worksheets (5 minutes).	d. After all the students have presented and received feedback from their peers, ask each student to write all the comments from the peers which they think are
e. Ask the representatives to present before the whole class their sketches and the	

complete chemical equation (16 minutes). f. Using the prepared rubric and the prompts, provide each sketch with feedback that students can use to improve their sketch (40 minutes). g. After all the teams have presented and received feedback from you (the teacher), ask each student to write all the comments from the teacher which they think are useful for them to improve their sketch. Let them write it on the worksheet (3 minutes). h. Let the students revise their sketches individually using the same materials (pens and colouring materials). Asked them to add complete and detailed labels to their sketches and to be specific when they mention “particles”, i.e., are they referring to atoms, ions, molecules, electrons, protons, or charges. Finally, asked them to write a detailed description of their sketch. i. Finally, asked the students to check if their revised sketch concurs with the	useful for them to improve their sketch. Let them write it on the worksheet (3 minutes). e. Let the students revise their sketches individually using the same materials (pens and colouring materials). Asked them to add complete and detailed labels to their sketches and to be specific when they mention "particles", i.e., are they referring to atoms, ions, molecules, electrons, protons, or charges. Finally, asked them to write a detailed description of their sketch. f. Finally, asked the students to check if their revised sketch concurs with the balanced chemical equation of the chemical reaction (15 minutes from e to f). g. Collect all the worksheets (1 minute).

balanced chemical equation of the chemical reaction (15 minutes from h to i). j. Collect all the worksheets (1 minute).	

Session 4: Decomposition reaction

Preparation:

1. Prepare all the laboratory apparatus and reagents needed before the class (one set for each team):
 - 5-mL hydrogen peroxide solution (35% w/v)
 - Small beaker
 - Match head size of manganese (IV) oxide/manganese dioxide (catalyst)
 - Glowing wooden splint
 - Colouring materials
 - Disposal container for the whole class
2. Reproduce copies of the worksheet for each student.
3. Before the session, ask the students to bring coloured pencils or crayons, plus coloured markers and manila paper (for the teacher-feedback group).

Procedure:

Day 1

1. Pre-activity (15 minutes)
 - a. Students will be working in teams with six to seven members for each team.
 - b. Present to the students the objective, materials, safety precautions and procedure of the practical work on the decomposition of hydrogen peroxide (see the worksheet).
2. Activity proper (Practical work) (30 minutes)
 - a. Let the students perform the practical work together as a team and take note of their macroscopic observations.

3. Post-activity

Sketching (45 minutes)

- a. After the conduct of the practical work, ask the students that if they can see what is happening to this reaction at the submicroscopic level, sketch what they could see before and after the reaction. Let the students sketch individually using their pens and colouring materials and put their sketches on the worksheet guided by a before-and-after table. Asked them to add complete and detailed labels to their sketches and to be specific when they mention “particles”, i.e., are they referring to atoms, ions, molecules, electrons, protons, or charges. Finally, asked them to write a detailed description of their sketch.

Day 2

Feedback (70-90 minutes)

Class A (Teacher-feedback)	Class B (Peer-feedback)
b. Ask each team to choose one representative who best represents the team's prediction of the products of the reaction (2 minutes).	b. Present the rubric and the prompts before the class. Tell them that these will be used by their peers to evaluate and improve their sketches. Tell them that these could be found in their worksheets (5 minutes).
c. Ask each team to copy the answers of the representative onto a manila paper to facilitate the whole-class presentation (8 minutes).	c. Let each student from each team present their sketch and their completed chemical equation to each other. Allow time for the presentation of each student (12-14 minutes) and for each peer to give feedback (30-35 minutes).
d. Present the rubric and the prompts before the class. Tell them, that these will be used by the teacher to evaluate and improve their sketches. Tell them that	

these could be found in their worksheets (5 minutes). e. Ask the representatives to present before the whole class their sketches and the complete chemical equation (16 minutes). f. Using the prepared rubric and the prompts, provide each sketch with feedback that students can use to improve their sketch (40 minutes). g. After all the teams have presented and received feedback from you (the teacher), ask each student to write all the comments from the teacher which they think are useful for them to improve their sketch. Let them write it on the worksheet (3 minutes). h. Let the students revise their sketches individually using the same materials (pens and colouring materials). Asked them to add complete and detailed labels to their sketches and to be specific when they mention “particles”, i.e., are they referring to atoms, ions, molecules, electrons, protons, or charges. Finally,	d. After all the students have presented and received feedback from their peers, ask each student to write all the comments from the peers which they think are useful for them to improve their sketch. Let them write it on the worksheet (3 minutes). e. Let the students revise their sketches individually using the same materials (pens and colouring materials). Asked them to add complete and detailed labels to their sketches and to be specific when they mention "particles", i.e., are they referring to atoms, ions, molecules, electrons, protons, or charges. Finally, asked them to write a detailed description of their sketch. f. Finally, asked the students to check if their revised sketch concurs with the balanced chemical equation of the chemical reaction (15 minutes from e to f). g. Collect all the worksheets (1 minute).

asked them to write a detailed description of their sketch. i. Finally, asked the students to check if their revised sketch concurs with the balanced chemical equation of the chemical reaction (15 minutes from h to i). j. Collect all the worksheets (1 minute).	

Session 5: Replacement reaction of metal in solution

Preparation:

1. Prepare all the laboratory apparatus and reagents needed before the class (one set for each team):
 - A piece of about 1-cm long magnesium
 - 0.1 M copper (II) chloride solution
 - Test tube
 - Test tube rack
 - Forceps
 - Colouring materials
 - Disposal container for the whole class
2. Reproduce copies of the worksheet for each student.
3. Before the session, ask the students to bring coloured pencils or crayons, plus coloured markers and manila paper (for the teacher-feedback group).

Procedure:

Day 1

1. Pre-activity (15 minutes)
 - a. Students will be working in teams with five members for each team.
 - b. Present to the students the objective, materials, safety precautions and procedure of the practical work on the reaction between magnesium and copper (II) chloride (see the worksheet).
2. Activity proper (Practical work) (30 minutes)
 - a. Let the students perform the practical work together as a team and take note of their macroscopic observations.

3. Post-activity

Sketching (45 minutes)

- a. After the conduct of the practical work, ask the students that if they can see what is happening to this reaction at the submicroscopic level, sketch what they could see before and after the reaction. Let the students sketch individually using their pens and coloured pencils and put their sketches on the worksheet guided by a before-and-after table. Asked them to add complete and detailed labels to their sketches and to be specific when they mention “particles”, i.e., are they referring to atoms, ions, molecules, electrons, protons, or charges. Finally, asked them to write a detailed description of their sketch.

Day 2

Feedback (70-90 minutes)

Class A (Teacher-feedback)	Class B (Peer-feedback)
b. Ask each team to choose one representative who best represents the team's prediction of the products of the reaction (2 minutes).	b. Present the rubric and the prompts before the class. Tell them that these will be used by their peers to evaluate and improve their sketches. Tell them that these could be found in their worksheets (5 minutes).
c. Ask each team to copy the answers of the representative onto a manila paper to facilitate the whole-class presentation (8 minutes).	c. Let each student from each team present their sketch and their completed chemical equation to each other. Allow time for the presentation of each student (12-14 minutes) and for each peer to give feedback (30-35 minutes).
d. Present the rubric and the prompts before the class. Tell them, that these will be used by the teacher to evaluate and improve their sketches. Tell them that	

these could be found in their worksheets (5 minutes). e. Ask the representatives to present before the whole class their sketches and the complete chemical equation (16 minutes). f. Using the prepared rubric and the prompts, provide each sketch with feedback that students can use to improve their sketch (40 minutes). g. After all the teams have presented and received feedback from you (the teacher), ask each student to write all the comments from the teacher which they think are useful for them to improve their sketch. Let them write it on the worksheet (3 minutes). h. Let the students revise their sketches individually using the same materials (pens and colouring materials). Asked them to add complete and detailed labels to their sketches and to be specific when they mention “particles”, i.e., are they referring to atoms, ions, molecules, electrons, protons, or charges. Finally,	d. After all the students have presented and received feedback from their peers, ask each student to write all the comments from the peers which they think are useful for them to improve their sketch. Let them write it on the worksheet (3 minutes). e. Let the students revise their sketches individually using the same materials (pens and colouring materials). Asked them to add complete and detailed labels to their sketches and to be specific when they mention "particles", i.e., are they referring to atoms, ions, molecules, electrons, protons, or charges. Finally, asked them to write a detailed description of their sketch. f. Finally, asked the students to check if their revised sketch concurs with the balanced chemical equation of the chemical reaction (15 minutes from e to f). g. Collect all the worksheets (1 minute).

asked them to write a detailed description of their sketch. i. Finally, asked the students to check if their revised sketch concurs with the balanced chemical equation of the chemical reaction (15 minutes from h to i). j. Collect all the worksheets (1 minute).	

Session 6: Double displacement reaction

Preparation:

1. Prepare all the laboratory apparatus and reagents needed before the class (one set for each team):
 - 1 gram of sodium sulfide
 - 5 mL of hydrochloric acid
 - Test tube
 - Pipette
 - Lead acetate paper strip (to test the product/s formed)
 - Colouring materials
 - 2 disposal containers for the whole class
2. Reproduce copies of the worksheet for each student.
3. Before the session, ask the students to bring coloured pencils or crayons, plus coloured markers and manila paper (for the teacher-feedback group).

Procedure:

1. Pre-activity (15 minutes)
 - a. Students will be working in teams with six to seven members for each team.
 - c. Present to the students the objective, materials, safety precautions and procedure of the practical work on the reaction between sodium sulfide and hydrochloric acid (see the worksheet).
2. Activity proper (Practical work) (30 minutes)
 - b. Let the students perform the practical work together as a team and take note of their macroscopic observations.

3. Post-activity

Sketching (45 minutes)

- a. After the conduct of the practical work, ask the students that if they can see what is happening to this reaction at the submicroscopic level, sketch what they could see before and after the reaction. Let the students sketch individually using their pens and colouring materials and put their sketches on the worksheet guided by a before-and-after table. Asked them to add complete and detailed labels to their sketches and to be specific when they mention “particles”, i.e., are they referring to atoms, ions, molecules, electrons, protons, or charges. Finally, asked them to write a detailed description of their sketch.

Day 2

Feedback (70-90 minutes)

Class A (Teacher-feedback)	Class B (Peer-feedback)
b. Ask each team to choose one representative who best represents the team's prediction of the products of the reaction (2 minutes).	b. Present the rubric and the prompts before the class. Tell them that these will be used by their peers to evaluate and improve their sketches. Tell them that these could be found in their worksheets (5 minutes).
c. Ask each team to copy the answers of the representative onto a manila paper to facilitate the whole-class presentation (8 minutes).	c. Let each student from each team present their sketch and their completed chemical equation to each other. Allow time for the presentation of each student (12-14 minutes) and for each peer to give feedback (30-35 minutes).
d. Present the rubric and the prompts before the class. Tell them, that these will be used by the teacher to evaluate and improve their sketches. Tell them that	

these could be found in their worksheets (5 minutes). e. Ask the representatives to present before the whole class their sketches and the complete chemical equation (16 minutes). f. Using the prepared rubric and the prompts, provide each sketch with feedback that students can use to improve their sketch (40 minutes). g. After all the teams have presented and received feedback from you (the teacher), ask each student to write all the comments from the teacher which they think are useful for them to improve their sketch. Let them write it on the worksheet (3 minutes). h. Let the students revise their sketches individually using the same materials (pens and colouring materials). Asked them to add complete and detailed labels to their sketches and to be specific when they mention "particles", i.e., are they referring to atoms, ions, molecules, electrons, protons, or charges. Finally,	d. After all the students have presented and received feedback from their peers, ask each student to write all the comments from the peers which they think are useful for them to improve their sketch. Let them write it on the worksheet (3 minutes). e. Let the students revise their sketches individually using the same materials (pens and colouring materials). Asked them to add complete and detailed labels to their sketches and to be specific when they mention "particles", i.e., are they referring to atoms, ions, molecules, electrons, protons, or charges. Finally, asked them to write a detailed description of their sketch. f. Finally, asked the students to check if their revised sketch concurs with the balanced chemical equation of the chemical reaction (15 minutes from e to f). g. Collect all the worksheets (1 minute).

asked them to write a detailed description of their sketch. i. Finally, asked the students to check if their revised sketch concurs with the balanced chemical equation of the chemical reaction (15 minutes from h to i). j. Collect all the worksheets (1 minute).	

- On giving feedback (teacher-feedback): Refer to the following instruction when giving feedback to your students.

1. The rubric for evaluating the sketches is given below. Refer to this when evaluating your students' sketches.

Rubric for Evaluating Sketches			
Criteria	Description		
	<i>Excellent</i>	<i>Good</i>	<i>Poor</i>
The sketch's representations of the criteria are...			
a. Identity of the chemical species involved in the reaction (e.g., atoms, ions, molecules, electrons, protons, and charges)		not so clear, have minor errors and some details are missing	difficult to understand, have major errors and many important details are missing
b. Conservation of atoms, before and after the reaction	clear, accurate and complete		
c. Arrangement of the chemical species based on the phases of the substances			
d. Distance among particles based on the phases of the substances			

2. When giving feedback to the students based on the rubric, consider the following delivery *moves*: adding detail, removing an idea, revising an idea, and finding out more about an idea. Decide which of the four delivery *moves* (or probably all of them) are applicable to help the students improve their sketches. Do not forget to justify the appropriateness of your comments. Below are prompts to help you deliver your feedback.

- a. Adding a detail: I think you need to add ...because ...This is based on...
- b. Removing an idea: I think you need to remove ... because ... This is based on ...
- c. Revising an idea: I think you need to revise ... because ... This is based on ...
- d. Finding out more about an idea: I think you might want to explain more about ... because ... This is based on ...

Appendix H Classroom Observation Checklists

Subject: General Chemistry I

Topic: Extraction of Iron (Practical Work) - Session 1

Date: November 20, 2018

Grade and Section: Grade 11 - STEM A

Time: 8:30 AM - 10:00 AM

Grade 11 - STEM B

11:00 AM - 12:30 PM

@ Physical Science Laboratory

Introduction: This checklist is constructed for the purpose of comparing the quality of how the two classes (teacher-feedback and peer-feedback) were conducted by the teacher. Please give your honest assessment based on the given criteria.

Direction: Please indicate the extent to which the researcher meets the criterion that are listed below. Place a check mark (✓) on the column corresponding to your observation.

Criterion	Strongly Disagree	Disagree	Agree	Strongly Agree
1.) The teacher made explicit the difference between the two conditions (teacher-feedback and peer-feedback).			✓	
2.) The teacher followed thoughtfully what is stated in the corresponding teacher's guide for the two classes.				✓
3.) For both classes, the teacher exhibited the same of personality and attitude.			✓	
4.) For both classes, the teacher used language and terminologies that students can easily understand.				✓
5.) For both classes, the teacher encouraged students to express their own ideas freely.				✓
6.) The teacher showed mastery of the subject matter in both classes.			✓	
7.) For both classes, the teacher-researcher exhibited mastery in delivering the lesson.	-		✓	
8.) The teacher:				
a.) gave both classes the same amount of activities (except for the feedback part), exercises, quizzes and assignments;				✓
b.) used the same medium of instruction to the two classes. Used English				✓

Comments and Suggestions:

- You may include students' behavior during the activity and/or discussion in both classes.
- STEM A class is quite/less organized than STEM B class.
- It was not helpful to have the lab apparatus placed in one corner of the room and ask a representative to get it (STEM A). It was helpful to have the lab apparatus already distributed in each lab table (STEM B). This facilitated the smooth flow of the session.
- There were 6 tables inside the lab and there were 8 groups. Groups 7 & 8 sat on the side (near the sink). That part of the room was quite crowded.
- Generally, all groups (all students) were engaged with the practical work and with the sketching.
 - You may also include justification or explanation for your observation.
- He probably ^{learned it} forgot that is why STEM A class was less organized than STEM B. Since we do not know what is going to happen, the execution/implementation was less systematic. Although, it improved during the second session (STEM B). Even the teacher became more ^{confident} about explaining important details about the sketching of submicroscopic entities during the second session (STEM B) compared to STEM A session.

Observer's Signature over Printed Name: _____

Galvez
Garry D. Galvez

Position: Researcher / PhD Candidate

Further observations:

- One student from STEM A responded that it's the first time they had a practical work in General Chemistry I. Sir Ronald, most of the time, uses lecture discussion to cover the topics.
- There are few students (exceptional students) from Group 1 of each class (those that got the highest score in the prior knowledge and spatial ability test) that 'almost' got the correct sketching of the reaction.
- Most groups found it difficult to notice the color change when iron (III) oxide - carbon mixture was heated. Some groups sought to repeat the activity.

Subject: General Chemistry I

Topic: Extraction of Iron (Giving Feedback) - Session 2

Date: November 27, 2018

Grade and Section: Grade II - STEM B

Time: 7:30 AM - 8:45 AM

Grade II - STEM A

9:00 AM - 10:30 AM

(at Biological Science Laboratory)

Introduction: This checklist is constructed for the purpose of comparing the quality of how the two classes (teacher-feedback and peer-feedback) were conducted by the teacher. Please give your honest assessment based on the given criteria.

Direction: Please indicate the extent to which the researcher meets the criterion that are listed below. Place a check mark (✓) on the column corresponding to your observation.

Criterion	Strongly Disagree	Disagree	Agree	Strongly Agree
1.) The teacher made explicit the difference between the two conditions (teacher-feedback and peer-feedback).				✓
2.) The teacher followed thoughtfully what is stated in the corresponding teacher's guide for the two classes.			✓	
3.) For both classes, the teacher exhibited the same of personality and attitude.				✓
4.) For both classes, the teacher used language and terminologies that students can easily understand.			✓	
5.) For both classes, the teacher encouraged students to express their own ideas freely.				✓
6.) The teacher showed mastery of the subject matter in both classes.				✓
7.) For both classes, the teacher-researcher exhibited mastery in delivering the lesson.	-		✓	
8.) The teacher:				
a.) gave both classes the same amount of activities (except for the feedback part), exercises, quizzes and assignments;				✓
b.) used the same medium of instruction to the two classes.				✓

Comments and Suggestions:

- You may include students' behavior during the activity and/or discussion in both classes.

STEM B

- Student-representatives (from each group) are very engaged and are well-versed in explaining their slides before the whole-class. Other groups of students are quiet, behave and are listening to the teacher while giving feedback and to the student presenters.
- We started at around 7:30 am (supposedly 7:00 am) because the teacher was late. Hence, we needed to adjust the time for the intervention so as not to disrupt the next class. The teacher allowed the students to submit the worksheets later in the afternoon. I felt that this would contain the teacher-feedback into peer-feedback.
- You may also include justification or explanation for your observation.

STEM A - Mr. and Mrs. Geraldine's son (young son of Mr. Ronald) was absent. Mr. Ronald needed to see Group 1 was chosen for video-recording because they are the most stable group - they follow the procedure efficiently than the other groups. Also, the best in the class are in the group. They finished giving peer-feedback quickly.

- Giving peer-feedback was a lot easier and faster compared to teacher-feedback.
- I, the researcher, needed to go in front of the class to explain how peer-feedback shall be delivered.

Observer's Signature over Printed Name:

Position: PhD Candidate / Researcher

Garry D. Galtres

- Mr. Ronald, the teacher was not very clear in explaining (in details and clearly) the rubric, prompts, concepts in a way that students could understand it fully. He just explains it in a way he understands it and for the sake of explaining it.
- Students from both classes are apparently busy with their practice/rehearsal for their spoken poetry class/performance. It is difficult to book a session with them. The teacher intended to make a schedule for the whole week and give it to students who are complete / finish all the sessions (incentive).

Subject: General Chemistry I

Topic: Reaction of Ethanoic Acid and Water (Practical Work) - Session 3 (Make-up class)

Date: November 27, 2018

Grade and Section: Grade 11 - STEM B

Time: 12:00 NN - 1:30 PM (Nov. 27, 2018)

Grade 11 - STEM A

1:30 PM - 2:45 PM (Nov. 28, 2018)

Physical Science Laboratory

Introduction: This checklist is constructed for the purpose of comparing the quality of how the two classes (teacher-feedback and peer-feedback) were conducted by the teacher. Please give your honest assessment based on the given criteria.

Direction: Please indicate the extent to which the researcher meets the criterion that are listed below. Place a check mark (✓) on the column corresponding to your observation.

Criterion	Strongly Disagree	Disagree	Agree	Strongly Agree
1.) The teacher made explicit the difference between the two conditions (teacher-feedback and peer-feedback).			✓	
2.) The teacher followed thoughtfully what is stated in the corresponding teacher's guide for the two classes.				✓
3.) For both classes, the teacher exhibited the same of personality and attitude.			✓	
4.) For both classes, the teacher used language and terminologies that students can easily understand.			✓	
5.) For both classes, the teacher encouraged students to express their own ideas freely.				✓
6.) The teacher showed mastery of the subject matter in both classes.				✓
7.) For both classes, the teacher-researcher exhibited mastery in delivering the lesson.			✓	
8.) The teacher:				
a.) gave both classes the same amount of activities (except for the feedback part), exercises, quizzes and assignments;				✓
b.) used the same medium of instruction to the two classes.				✓

Comments and Suggestions:

- You may include students' behavior during the activity and/or discussion in both classes.

STEM B

- I had a lapid about the reaction of ethanoic acid or acid and phenolphthalein. I thought that it would turn pink with acids. What happened was, no color change was observed by the student bec. its reaction with acids is actually colorless. Even the teacher got confused about it and got a book to verify it.
- The teacher told me that students don't have any idea yet about dissociation rxn particularly that of a weak acid. Although to help students he gave leading information to make the students realize that weak acids or acid produce H^+ ions in a solution that combine with H_2O to form H_3O^+ .
- You may also include justification or explanation for your observation.
- Although, students do not have really a general idea of class (since their planner are over, i.e. only until 12 NN), they were still engaged with the practical work & sketching.

STEM A

- Students just came in from a performance (I think upstages party) in the morning. It appears that they are so tired. When students came to the front of the class to dispense the reagents for their group, group members sitting on the tables are so sleeping.

Observer's Signature over Printed Name: _____

Granny D. Gualves

Position: PhD Candidate/Researcher

- The ethanoic acid that I brought were all used up, that's why the class used the student acetic acid. And the room was filled with a "vinegar smell". This stimulated noise, smiles, laughter, jokes and made the class alive.
- The teacher before explaining the procedure of the practical work did give a hint about what acid is and how it dissociates particularly a weak acid. This may have appeared to contaminate peer-feedback with teacher-feedback yet he did this because students have very limited prior knowledge on ionization of acids.

Subject: General Chemistry I

Topic: Reaction of Ethanoic Acid and Water (Giving Feedback) - Session 4 (Make-up class)

Date: November 28, 2018

Grade and Section: Grade 11 - STEM B

Time: 12:50 NN - 1:50 PM

Grade 11 - STEM A

2:45 PM - 3:45 PM

Physics Science Laboratory

Introduction: This checklist is constructed for the purpose of comparing the quality of how the two classes (teacher-feedback and peer-feedback) were conducted by the teacher. Please give your honest assessment based on the given criteria.

Direction: Please indicate the extent to which the researcher meets the criterion that are listed below. Place a check mark (✓) on the column corresponding to your observation.

Criterion	Strongly Disagree	Disagree	Agree	Strongly Agree
1.) The teacher made explicit the difference between the two conditions (teacher-feedback and peer-feedback).				✓
2.) The teacher followed thoughtfully what is stated in the corresponding teacher's guide for the two classes.			✓	
3.) For both classes, the teacher exhibited the same of personality and attitude.				✓
4.) For both classes, the teacher used language and terminologies that students can easily understand.			✓	
5.) For both classes, the teacher encouraged students to express their own ideas freely.				✓
6.) The teacher showed mastery of the subject matter in both classes.				✓
7.) For both classes, the teacher-researcher exhibited mastery in delivering the lesson.				✓
8.) The teacher:				
a.) gave both classes the same amount of activities (except for the feedback part), exercises, quizzes and assignments;				✓
b.) used the same medium of instruction to the two classes.				✓

Although STEM A (peer-feedback) tend to give feedback in Filipino and STEM B (teacher-feedback) tend to explain their sketches in English and received feedback from the teacher in English.

Comments and Suggestions:

- You may include students' behavior during the activity and/or discussion in both classes.

STEM B

- The students are very engaged in receiving feedback from their teacher. I even used Group 5 students standing and taking down notes of the feedback given.
- After each group has presented their sketch before the class and received teacher feedback, the teacher instructed them to immediately start with the revision of sketch.
- In session 1, presentations started from Group 1 to Group 8. In session 2, it started from Group 8 to Group 1.

- You may also include justification or explanation for your observation.

STEM A

- It appears that most students are sleepy and tired (restless). They did not execute peer-feedback seriously. Group 2 made the same feedback written on their worksheets. They said that it is bec. they have the same sketch.
- I noticed that some students are too lazy to give feedback. Group F is the person of Fernando Reyes is misbehaving, not paying attention and is only copying his peer's work.
- Group 1 (the one being videotaped) is the last to finish. They tried their best to come up with their best work.

Observer's Signature over Printed Name: _____

Garry U. Giatre

Position: PhD Candidate / Researcher

sketch and follow the peer-feedback protocol.

- The teacher also appears to be tired that he no longer cares about what the class are doing towards the end of the class. He even noted to execute the peer-feedback.

Subject: General Chemistry I

Topic: Combination/Synthesis Reaction (Practical Work & Giving Feedback) - Session 5 & 6

Date: November 29, 2018

Grade and Section: Grade 11 - STEM A

Time: 8:20 AM - 10:00 AM

Grade 11 - STEM B

10:20 AM - 12:00 NN

Physical Science Laboratory

Introduction: This checklist is constructed for the purpose of comparing the quality of how the two classes (teacher-feedback and peer-feedback) were conducted by the teacher. Please give your honest assessment based on the given criteria.

Direction: Please indicate the extent to which the researcher meets the criterion that are listed below. Place a check mark (✓) on the column corresponding to your observation.

Criterion	Strongly Disagree	Disagree	Agree	Strongly Agree
1.) The teacher made explicit the difference between the two conditions (teacher-feedback and peer-feedback).				✓
2.) The teacher followed thoughtfully what is stated in the corresponding teacher's guide for the two classes.			✓	
3.) For both classes, the teacher exhibited the same of personality and attitude.				✓
4.) For both classes, the teacher used language and terminologies that students can easily understand.			✓	
5.) For both classes, the teacher encouraged students to express their own ideas freely.				✓
6.) The teacher showed mastery of the subject matter in both classes.				✓
7.) For both classes, the teacher ~~researcher~~ exhibited mastery in delivering the lesson.				✓
8.) The teacher:				
a.) gave both classes the same amount of activities (except for the feedback part), exercises, quizzes and assignments;				✓
b.) used the same medium of instruction to the two classes.				✓

Comments and Suggestions:

- * You may include students' behavior during the activity and/or discussion in both classes.
- Both STEM A + B students enjoyed the practical work of burning magnesium to oxidize it then reactants used the production of white bright light
- Order of presentation for teacher-feedback: Group 5, 4, 3, 2, 1, 8, 7, 6
- Sir (Donald) was able to give the feedback that students could change color to indicate changes from before to now
- Students from both classes were happy with the new sketching task because they don't need to predict products of the rxn. Sir Donald used that already to students, predicting products of rxn is difficult.
- It appears that the intervention becomes more automated to the students and the teacher they are more familiar with the steps and they are more keen on following the steps correctly and completely.

Observer's Signature over Printed Name:

Position: PhD Candidate/Researcher

Gary D. Galvez

Subject: General Chemistry I

Topic: Decomposition reaction (Practical Work) - Section 7 (Make-up class)

Date: December 03, 2018

Grade and Section: Grade 11 - STEM A

Time: 12:00 PM - 1:00 PM

Grade 11 - STEM B

1:30 PM - 2:30 PM

@ Physical Science Laboratory

Introduction: This checklist is constructed for the purpose of comparing the quality of how the two classes (teacher-feedback and peer-feedback) were conducted by the teacher. Please give your honest assessment based on the given criteria.

Direction: Please indicate the extent to which the researcher meets the criterion that are listed below. Place a check mark (✓) on the column corresponding to your observation.

Criterion	Strongly Disagree	Disagree	Agree	Strongly Agree
1.) The teacher made explicit the difference between the two conditions (teacher-feedback and peer-feedback).				✓
2.) The teacher followed thoughtfully what is stated in the corresponding teacher's guide for the two classes.				✓
3.) For both classes, the teacher exhibited the same of personality and attitude.			✓	
4.) For both classes, the teacher used language and terminologies that students can easily understand.			✓	
5.) For both classes, the teacher encouraged students to express their own ideas freely.				✓
6.) The teacher showed mastery of the subject matter in both classes.				✓
7.) For both classes, the teacher-researcher exhibited mastery in delivering the lesson.	-			✓
8.) The teacher:				
a.) gave both classes the same amount of activities (except for the feedback part), exercises, quizzes and assignments;				✓
b.) used the same medium of instruction to the two classes.				✓

Comments and Suggestions:

- You may include students' behavior during the activity and/or discussion in both classes.

STEM A

- The teacher left the class after explaining what to do with the practical work. I needed to facilitate the practical work without actually "teaching" only trying to make the students perform the practical work. The teacher has an underlying chore and is administering an exam. He then returns to take over. The students were restless when the teacher was away.

- You may also include justification or explanation for your observation.

STEM B

- The teacher was late because he needed to take his lunch.
- Group 8 was not able to observe accurately the decomposition of H_2O_2 because of lack of reagents (not enough supply). Although the teacher tried to provide a part of what I brought, we think it's already a decomposed H_2O_2 (into H_2O) because we saw bubbles and was observed.

Observer's Signature over Printed Name:

Garry D. Garlvez

Position: PhD Candidate / Researcher

- I noticed that in both classes, a number of students were missing/excused. They are practicing for a sports competition. This is the first time I had this observation.

Subject: General Chemistry I

Topic: Decomposed reaction (Giving feedback) - Session 8

Date: December 04, 2018

Grade and Section: Grade 11- STEM B

Time: 7:00 AM - 8:30 AM

Grade 11- STEM A

8:30 AM - 10:00 AM

@ Biological Science Laboratory

Introduction: This checklist is constructed for the purpose of comparing the quality of how the two classes (teacher-feedback and peer-feedback) were conducted by the teacher. Please give your honest assessment based on the given criteria.

Direction: Please indicate the extent to which the researcher meets the criterion that are listed below. Place a check mark (✓) on the column corresponding to your observation.

Criterion	Strongly Disagree	Disagree	Agree	Strongly Agree
1.) The teacher made explicit the difference between the two conditions (teacher-feedback and peer-feedback).			✓	
2.) The teacher followed thoughtfully what is stated in the corresponding teacher's guide for the two classes.			✓	
3.) For both classes, the teacher exhibited the same of personality and attitude.				✓
4.) For both classes, the teacher used language and terminologies that students can easily understand.			✓	
5.) For both classes, the teacher encouraged students to express their own ideas freely.				✓
6.) The teacher showed mastery of the subject matter in both classes.				✓
7.) For both classes, the teacher-researcher exhibited mastery in delivering the lesson.				✓
8.) The teacher:				
a.) gave both classes the same amount of activities (except for the feedback part), exercises, quizzes and assignments;				✓
b.) used the same medium of instruction to the two classes.				✓

Comments and Suggestions:

- You may include students' behavior during the activity and/or discussion in both classes.

STEM B

- They finished giving feedback 15 minutes early. Hence, the teacher had the time to discuss the subtypes of decomposition rep.
- Presentations started with Group 4, 3, 2, 1, 8, 7, 6, 5
- A number of students are late comers.

- You may also include justification or explanation for your observation.

STEM A

- They finished giving feedback 30 min. early. Hence, the teacher took the time to discuss the subtypes of combination rep.
- They really give peer feedback quickly/shortly. It does not take them too much time to give peer feedback.

Observer's Signature over Printed Name: _____

Garry D. Galvez

Position: PhD Candidate / Researcher

Subject: General Chemistry I

Topic: Replacement reaction of a metal in solution (Practical work) - Section 9 (Make-up class)

Date: December 04, 2018

Grade and Section: Grade 11 - STEM B

Time: 12:00 NN - 1:00 PM

Grade 11 - STEM A

1:30 PM - 2:30 PM

@ Physical Science Laboratory

Introduction: This checklist is constructed for the purpose of comparing the quality of how the two classes (teacher-feedback and peer-feedback) were conducted by the teacher. Please give your honest assessment based on the given criteria.

Direction: Please indicate the extent to which the researcher meets the criterion that are listed below. Place a check mark (✓) on the column corresponding to your observation.

Criterion	Strongly Disagree	Disagree	Agree	Strongly Agree
1.) The teacher made explicit the difference between the two conditions (teacher-feedback and peer-feedback).				✓
2.) The teacher followed thoughtfully what is stated in the corresponding teacher's guide for the two classes.				✓
3.) For both classes, the teacher exhibited the same of personality and attitude.				✓
4.) For both classes, the teacher used language and terminologies that students can easily understand.			✓	
5.) For both classes, the teacher encouraged students to express their own ideas freely.				✓
6.) The teacher showed mastery of the subject matter in both classes.				✓
7.) For both classes, the teacher ~~researcher~~ exhibited mastery in delivering the lesson.	-			✓
8.) The teacher:				
a.) gave both classes the same amount of activities (except for the feedback part), exercises, quizzes and assignments;				✓
b.) used the same medium of instruction to the two classes.				

Comments and Suggestions:

- You may include students' behavior during the activity and/or discussion in both classes.
- Although the students are called for a "make up class" in which normally they are restless and find hard they don't take the class seriously, this time they enjoyed the red between Mg & $CuCl_2$ due to its dramatic observation (evidence of chemical change). Students display dramatic chemical rxns. They are also fascinated with the deep clear blue color of the $CuCl_2$ soln.
- Some students find both classes very boring due to practice of various players.

- You may also include justification or explanation for your observation.
- I also noticed that their sketches during this activity has more errors as compared to the previous tasks (sketching). Students represented $CuCl_2$ & $MgCl_2$ as molecules not as ions as required. They are "conditioned" that this is the way they are represented as they did from their previous sketching tasks (i.e. H_2O_2 , H_2O , O_2)

Observer's Signature over Printed Name: _____

Garry D. Galvez

Position: PhD Candidate/Researcher

Subject: General Chemistry I

Topic: Replacement reaction of a metal in solution (Giving feedback) - Sec 10 (Make-up Class)

Date: December 05, 2018

Grade and Section: Grade 11 - STEM A @ Chemistry Laboratory Time: 2:00 PM - 3:00 PM
Grade 11 - STEM B @ Physical Science Laboratory 3:00 PM - 4:00 PM

Introduction: This checklist is constructed for the purpose of comparing the quality of how the two classes (teacher-feedback and peer-feedback) were conducted by the teacher. Please give your honest assessment based on the given criteria.

Direction: Please indicate the extent to which the researcher meets the criterion that are listed below. Place a check mark (✓) on the column corresponding to your observation.

Criterion	Strongly Disagree	Disagree	Agree	Strongly Agree
1.) The teacher made explicit the difference between the two conditions (teacher-feedback and peer-feedback).				✓
2.) The teacher followed thoughtfully what is stated in the corresponding teacher's guide for the two classes.			✓	
3.) For both classes, the teacher exhibited the same of personality and attitude. <i>(A little tired and is a hurry)</i>				✓
4.) For both classes, the teacher used language and terminologies that students can easily understand.			✓	
5.) For both classes, the teacher encouraged students to express their own ideas freely.				✓
6.) The teacher showed mastery of the subject matter in both classes.				✓
7.) For both classes, the teacher-researcher exhibited mastery in delivering the lesson.	-			✓
8.) The teacher:				
a.) gave both classes the same amount of activities (except for the feedback part), exercises, quizzes and assignments;				✓
b.) used the same medium of instruction to the two classes.				✓

Comments and Suggestions:

- You may include students' behavior during the activity and/or discussion in both classes.

STEM A

- We were displaced from the Physical Science room. We transferred to the Chemistry Lab where it was quite hot/warm. Students do not want to hold the class there.
- The teacher did give feedback to one of the groups (Group 4) about CuCl_2 and MgCl_2 not being molecular but rather as ions in solution. That is why Group 4 was the only group to sketch the existence of ions in solution.
- It appears that the teacher is in a hurry. You may also include justification or explanation for your observation.
- It appears that peer feedback did not help revise the sketches of the student in terms of having ions in solution - CuCl_2 & MgCl_2 . They still drew them as molecular compounds.

Observer's Signature over Printed Name:

Garry D. Galvez

Position: PhD Candidate / Researcher

- The teacher commented + change color of magnesium (transition ions) → we came back to the Physical Science Lab (air conditioned).
- STEM B → Order of presentation: Grp. 1, 2, 3, 4, 5, 6, 7, (8) → lot to find / lot to submit / lot to leave the room
- According to the teacher, 3x that students approached was asking that we postpone the meeting/class for today.
- Although the teacher gave feedback about MgCl_2 & CuCl_2 being ions in solution and not molecular compounds, students failed to sketch it. Instead they sketched Cl_2 and Cl^- in solution but as molecular diatomic species. The message did not translate effectively?
- It appears that the teacher is in a hurry. He asked those students who finished revising their sketches first to leave the room (that they can leave) thereby putting pressure + giving priority for those who are left behind.
- One student was sleeping (apparently) i.e. a varsity player from practice who decided to attend the class. Yet he tried his best to revise correctly the sketch and seek the teacher's approval as to the accuracy of his sketch.
- A number of students left the room later than others bec. they tried to clarify if Cl_2 should separate or not. When they ask me about it, I ask them to see the teacher.
- One student knew this and she decided to revise her sketch next class session (formal).
- To one group who asked me (Group 8), I repeated to them what the teacher commented.

Subject: General Chemistry I

Topic: Double Displacement Reaction (Practical Work) - Session 11

Date: December 06, 2018

Grade and Section: Grade 11 - STEM A

Time: 8:30 AM - 10:00 AM

Grade 11 - STEM B
(2 Physical Science Laboratory)

10:30 AM - 12:00 NN

Introduction: This checklist is constructed for the purpose of comparing the quality of how the two classes (teacher-feedback and peer-feedback) were conducted by the teacher. Please give your honest assessment based on the given criteria.

Direction: Please indicate the extent to which the researcher meets the criterion that are listed below. Place a check mark (✓) on the column corresponding to your observation.

Criterion	Strongly Disagree	Disagree	Agree	Strongly Agree
1.) The teacher made explicit the difference between the two conditions (teacher-feedback and peer-feedback).			✓	
2.) The teacher followed thoughtfully what is stated in the corresponding teacher's guide for the two classes.			✓	
3.) For both classes, the teacher exhibited the same of personality and attitude.				✓
4.) For both classes, the teacher used language and terminologies that students can easily understand.			✓	
5.) For both classes, the teacher encouraged students to express their own ideas freely.				✓
6.) The teacher showed mastery of the subject matter in both classes.				✓
7.) For both classes, the teacher-researcher exhibited mastery in delivering the lesson.	-			✓
8.) The teacher:				
a.) gave both classes the same amount of activities (except for the feedback part), exercises, quizzes and assignments;				✓
b.) used the same medium of instruction to the two classes.				✓

Comments and Suggestions:

- You may include students' behavior during the activity and/or discussion in both classes.

STEM A & B

- There was a little "chaos" due to the foul odor of H_2S produced from the practical work. Students went out of the room to avoid the smell. The teacher also went out. The room was allowed to have the air circulate (windows and doors were opened).
- It appears that students did enjoy the lab activity. All of them were engaged with speaking the rxn. One factor for this might be the idea that they knew that this is the last practical work or told by the teacher.
- You may also include justification or explanation for your observation.
- Few students are still missing because of their practical (varsity players)

Observer's Signature over Printed Name:

Garry D. Galvez
Garry D. Galvez

Position: PhD Candidate/Researcher

Subject: General Chemistry I

Topic: Double Displacement Reaction (Giving Feedback) - Session 12 (Make-up class)

Date: December 06, 2018

Grade and Section: Grade 11 - STEM A

Time: 1:00 PM - 2:00 PM

Grade 11 - STEM B

2:00 PM - 3:00 PM

Introduction: This checklist is constructed for the purpose of comparing the quality of how the two classes (teacher-feedback and peer-feedback) were conducted by the teacher. Please give your honest assessment based on the given criteria.

Direction: Please indicate the extent to which the researcher meets the criterion that are listed below. Place a check mark (✓) on the column corresponding to your observation.

Criterion	Strongly Disagree	Disagree	Agree	Strongly Agree
1.) The teacher made explicit the difference between the two conditions (teacher-feedback and peer-feedback).				✓
2.) The teacher followed thoughtfully what is stated in the corresponding teacher's guide for the two classes.			✓	
3.) For both classes, the teacher exhibited the same of personality and attitude.				✓
4.) For both classes, the teacher used language and terminologies that students can easily understand.			✓	
5.) For both classes, the teacher encouraged students to express their own ideas freely.				✓
6.) The teacher showed mastery of the subject matter in both classes.				✓
7.) For both classes, the teacher-researcher exhibited mastery in delivering the lesson.	-			✓
8.) The teacher:				
a.) gave both classes the same amount of activities (except for the feedback part), exercises, quizzes and assignments;				✓
b.) used the same medium of instruction to the two classes.				✓

Comments and Suggestions:

- You may include students' behavior during the activity and/or discussion in both classes.

STEM A

- They have been contaminated with teacher feedback. The teacher gave comments on his HCl + NaCl exist in solids. The teacher told this to Group 6 and Group 6 made it known to few members of Group 5. Although majority of Group 5 and the class didn't learn about this teacher feedback.
- Students are engaged with giving feedback yet they give feedback very swift and short.
- You may also include justification or explanation for your observation.
- Common observation that students take shorter time to revise their sketches that do it from scratch.

STEM B

- The teacher is really a content master. The problem is that his ideas / discussion of key concepts do not translate so that students could improve their sketch. Write a number could follow but not all. Like Group 3 who still after revision / the group does H₂S or ions in a

Observer's Signature over Printed Name:

Garry D. Galvez

Position: PhD Candidate / Researcher

formula unit / crystal unit not as molecular.

- The class was quite noisy in the beginning. They were also restless although the teacher would frequently call their attention. Yet, after the teacher has given feedback, the students were engaged with revising their sketches. This took them shorter time than to sketch from scratch.
- There were quite a few late students at the beginning of the session. The teacher started without them. Yet, he finally decided to wait as students keep coming one by one.
- In a quick conversation with a student, she mentioned that these students might be late because they haven't take lunch yet. Some decided to eat yet others like them would not like to finish the session and go home early to eat lunch. Hence, I think and admire their cooperation. Despite these hurdles, they showed me real cooperation with the tasks.

Appendix I.1 The University of Hong Kong Ethics Approval

THE UNIVERSITY OF HONG KONG



July 30, 2018

Mr. Garry Galvez
PhD Student
Faculty of Education

Dear Mr. Galvez,

Application for Ethics Approval
HREC's Reference Number: EA1807023

I refer to your application for ethics approval of your project entitled "Sketching coupled with feedback: Effects on Filipino senior high school students' submicroscopic understanding of chemical reactions".

2. I am pleased to inform you that the application has been approved by the Human Research Ethics Committee (HREC) regarding the ethical aspect of the above-mentioned research project, and the expiration date of the ethical approval is July 29, 2022.
3. Starting from April 1, 2015, the HREC's reference number of your project (i.e. EA1807023) has to be shown in all materials sent to potential and actual participants to enable participants to link the materials to an approved project.
4. You are reminded to report to the Committee any amendments and new information on the project. Any deviation from the study protocol or compliance incident that has occurred during a study and may adversely affect the rights, safety or well-being of any participant or breaches of confidentiality should be reported to the HREC within 15 calendar days from the first awareness of the deviation/incident by the PI. Application for amendment(s) of an approved project including project extension should be submitted using a prescribed form which can be downloaded from the Research Services homepage (<http://www.rss.hku.hk/integrity/ethics-compliance/hrec>). Application for extension should be submitted well before the initially approved expiration date.

Yours sincerely,

Professor J.H. Bacon-Shone
Chairman
Human Research Ethics Committee

c.c. Dr. M.M.W. Cheng, Faculty of Education
Office of Research, Faculty of Education

JBS/cw/bw

THE REGISTRY 教務處

POKFULAM ROAD, HONG KONG. TEL: (852) 2859 2111 FAX: (852) 2858 2549

Appendix I.2 The University of Waikato Ethics Approval

Dean's Office
Faculty of Education
Te Kura Toi Tangata
The University of Waikato
Private Bag 3105
Hamilton, New Zealand

Phone +64 7 838 4500
www.waikato.ac.nz



THE UNIVERSITY OF
WAIKATO
Te Hāuaere Hīmango o Waikato

MEMORANDUM

To: Garry Galvez
cc: AProf Maurice Cheng
From: Dr Nicola Daly and Dr Sonja Arndt
Co-chair Faculty of Education Research Ethics Committee
Date: 20/2/19

Request for Extension to Research Ethics Approval – Student (MFEDU001/19)

Thank you for your request for an extension to the ethics approval for the project:

Sketching coupled with feedback: Effects on Filipino senior high school students' submicroscopic understanding of chemical reactions

Thank you for your memo outlining the differences between the ethical approval requirements for your PhD research from Hong Kong University and those required by The Faculty of Education Ethics Committee at the University of Waikato.

We note that, on the whole, the ethical requirements are very similar.

The following minor differences between the two ethics application requirements are noted:

- You were required to keep your data for three years by HKU and not 5 years as we require at the University of Waikato.
- In your HKU application you were not required to inform your participants of where they can receive information about your findings.
- You were not required to outline language and cultural considerations in your HKU application, but that you have noted that as a Filipino chemistry teacher, you have a similar cultural and language background to your participants.
- No statement on ownership of data was needed in your HKU application

Given that your research is low risk (involving interviewing participants), and that your data has already been collected under the HKU requirements, we are prepared to ratify the ethical approval from Hong Kong University, on the following conditions:

1. In the reporting of your data, please find a way to give your participants access to your findings in a manner suitable for your context.
2. In your thesis please note that ethical approval for data collection was given by HKU university, and that we have ratified the approval as part of your transfer to the University of Waikato. Please include a copy of the attached ratification memo in your thesis.

We wish you all the best as you write up your thesis at the University of Waikato.

Sonja Arndt and Nicola Daly

Nicola Daly

Sonja Arndt

Dr Nicola Daly and Dr Sonja Arndt
Co-chair Faculty of Education Research Ethics Committee

Appendix J Copyright Permissions on the Use of Tables and Figures

gg48@students.waikato.ac.nz

(+64)022 174 88 00

James Nyachwaya, PhD

School of Education and

Department of Chemistry and Biochemistry

North Dakota State University

Dear Associate Professor Nyachwaya,

My name is Garry Galvez. I am a Doctoral student at The University of Waikato in New Zealand, and am writing a thesis on drawing for my PhD in Science Education. A print copy of this thesis when completed will be deposited in the University Library, and a digital copy will also be made available online via the University's digital repository, Research Commons. This is a not-for-profit research repository for scholarly work which is intended to make research undertaken in the University available to as wide an audience as possible.

I am writing to request permission for the following work, for which I believe you hold the copyright, to be included in my thesis:

Nyachwaya, J. M., Mohamed, A. R., Rochrig, G. H., Wood, N. B., Kern, A. L., & Schneider, J. L. (2011). The development of an open-ended drawing tool: An alternative diagnostic tool for assessing students' understanding of the particulate nature of matter. *Chemistry Education Research and Practice*, 12(2), 121-132. <https://doi.org/https://doi.org/10.1039/C1RP90017J>

Figure 3 Open-ended drawing response questions - Nos. 2a and 2b; and

Figure 4 Particulate diagram responses to the three questions from one student - Q2

I am seeking from you a non-exclusive licence for an indefinite period to include these materials in the print and electronic copies of my thesis. The materials will be fully and correctly referenced.

If you agree, I should be very grateful if you would sign the form attached and return a copy to me. If you do not agree, or if you do not hold the copyright in this work, would you please notify me of this. I can most quickly be reached at this email address: gg48@students.waikato.ac.nz

Thank you for your assistance. I look forward to hearing from you.

Yours sincerely,

Garry Galvez

I James Nyachwaya agree to grant you a non-exclusive licence for an indefinite period to include the above materials, for which I am the copyright owner, in the print and digital copies of your thesis.

Date: 12/28/2021

gg48@students.waikato.ac.nz

(+64)022 174 88 00

Anne Liu Kern, PhD

COE-Curriculum and Instruction, Science Education

University of Idaho, Coeur d'Alene campus

1031 Academic Way, Coeur d'Alene, ID 83814, USA

Dear Professor Kern,

My name is Garry Galvez. I am a Doctoral student at The University of Waikato in New Zealand, and am writing a thesis on drawing for my PhD in Science Education. A print copy of this thesis when completed will be deposited in the University Library, and a digital copy will also be made available online via the University's digital repository, Research Commons. This is a not-for-profit research repository for scholarly work which is intended to make research undertaken in the University available to as wide an audience as possible.

I am writing to request permission for the following work, for which I believe you hold the copyright, to be included in my thesis:

Kern, A. L., Wood, N. B., Roehrig, G. H., & Nyachwaya, J. (2010). A qualitative report of the ways high school chemistry students attempt to represent a chemical reaction at the atomic/molecular level. *Chemistry Education Research and Practice*, 11(3), 165-172. <https://doi.org/https://doi.org/10.1039/C005465H>

Figure 1 The test-item used to elicit students' particulate representations of a chemical reaction, p. 167; and

Table 1 Sample responses within the discrete atoms – matching formula sub-theme, the drawing for 'Balanced (16.3%)', p. 168

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If you agree, I should be very grateful if you would sign the form attached and return a copy to me. If you do not agree, or if you do not hold the copyright in this work, would you please notify me of this. I can most quickly be reached at this email address: gg48@students.waikato.ac.nz

Thank you for your assistance. I look forward to hearing from you.

Yours sincerely,

Garry Galvez

I Anne Kern agree to grant you a non-exclusive licence for an indefinite period to include the above materials, for which I am the copyright owner, in the print and digital copies of your thesis.

Date: December 27, 2021

Appendix K.1 Scoring Rubrics for the Worksheets and Recall Test

Session 1: Burning of magnesium

Full score: 22 pts.	Score	Mg (Metallic Crystal) represented as	O ₂ (Diatomic Gas) represented as	MgO (Ionic Crystal) represented as
VISUAL (9 pts.)				
Identity of the species (7 pts.)	3		diatomic molecule	Mg ²⁺ and O ²⁻ ions
	2		discrete atom	Mg and O ions
	1	atom	diatomic ion	Mg ²⁺ and O ²⁻ ions
	0	ion	discrete ion	molecule
Conservation of particles (2 pts.)	2	No. of Mg and O particles before the reaction = No. of Mg and O particles after the reaction as based on the balanced chemical equation		
	1	No. of Mg (or O) particles before the reaction = No. of Mg (or O) particles after the reaction as based on the balanced chemical equation		
	0	No. of Mg and O particles before the reaction ≠ No. of Mg and O particles after the reaction as based on the balanced chemical equation		
SPATIAL (13 pts.)				
Arrangement of the particles (7 pts.)	3			alternating Mg and O particles in a regular way
	2	stacked above each other in a regular way	irregularly scattered	alternating Mg and O particles in an irregular way
	1	stacked above each other in an irregular way	regularly scattered	alternating columns or rows of Mg and O particles
	0	not stacked above each other or scattered	not scattered	not alternating or as scattered Mg and O particles
Distance between particles (6 pts.)	2	particles that are close to each other	particles that have empty spaces between each	Mg and O particles that are close to each other
	1	particles that are close to each other but have little	particles that have empty spaces between each	Mg and O particles that are close to each other but have
	0	particles that have wide empty spaces between	particles that are close to each other	Mg and O particles that have wide empty spaces between

Session 2: Decomposition of hydrogen peroxide

Full score: 29 pts.	Score	H ₂ O ₂ (in Aqueous Solution) represented as	H ₂ O (Liquid) represented as	O ₂ (Diatomic Gas) represented as
VISUAL (15 pts.)				
Identity of the species (13 pts.)	5	molecule	molecule	
	4	separate O ₂ and H ₂ O diatomic molecules	H ₂ O diatomic molecule	
	3	discrete O and H atoms	discrete O and H atoms	diatomic molecule
	2	bonded O and H ions	bonded O and H ions	discrete atom
	1	separate O ₂ and H ₂ O diatomic ions	H ₂ O diatomic ions	diatomic ion
	0	discrete O and H ions	discrete O and H ions	discrete ion
Conservation of particles (2 pts.)	2	No. of H and O particles before the reaction = No. of H and O particles after the reaction as based on the balanced chemical equation		
	1	No. of H (or O) particles before the reaction = No. of H (or O) particles after the reaction as based on the balanced chemical equation		
	0	No. of H and O particles before the reaction ≠ No. of H and O particles after the reaction as based on the balanced chemical equation		
SPATIAL (14 pts.)				
Arrangement of the particles (6 pts.)	2	irregularly scattered	irregularly scattered	irregularly scattered
	1	regularly scattered	regularly scattered	regularly scattered
	0	not scattered	not scattered	not scattered
Distance between particles (8 pts.)	3	particles that have little empty spaces between	particles that have little empty spaces between	
	2	particles that have wide empty spaces between	particles that have wide empty spaces between	particles that have empty spaces between each other and
	1	particles that have wide empty spaces between each other comparable to (or more than) that of O ₂ gas	particles that have wide empty spaces between each other comparable to (or more than) that of O ₂ gas	particles that have empty spaces between each other comparable (or less) to that of H ₂ O solution and liquid H ₂ O
	0	particles that are close to each other	particles that are close to each other	particles that are close to each other

Session 3: Reaction between magnesium and copper (II) chloride

Full score: 31 points	Score	Mg (Metallic Crystal) represented as	CuCl ₂ (Ions in Solution) represented as	Cu (Metallic Crystal) represented as	MgCl ₂ (Ions in Solution) represented as
VISUAL (13 pts.)					
Identity of the species (10 pts.)	4		discrete Cu ²⁺ and Cl ⁻ ions		discrete Mg ²⁺ and Cl ⁻ ions
	3		discrete Cu and Cl ²⁻ ions		discrete Mg and Cl ²⁻ ions
	2		bonded Cu ²⁺ and Cl ⁻ ions		bonded Mg ²⁺ and Cl ⁻ ions
	1	atom	discrete Cu and Cl atoms	atom	discrete Mg and Cl atoms
	0	ion	CuCl molecule	ion	MgCl molecule
Conservation of particles (3 pts.)	3	No. of Mg, Cu and Cl particles before the reaction = No. of Mg, Cu and Cl particles after the reaction as based on the balanced chemical equation			
	2	No. of particles of any 2 of the 3 species are equal before and after the reaction as based on the balanced chemical equation			
	1	No. of particles of any 1 of the 3 species are equal before and after the reaction as based on the balanced chemical equation			
	0	No. of particles of all 3 species are not equal before and after the reaction as based on the balanced chemical equation			
SPATIAL (18 pts.)					
Arrangement of the particles (8 pts.)	2	stacked above each other in a regular	irregularly scattered	stacked above each other in a regular	irregularly scattered
	1	stacked above each other in an irregular	regularly scattered	stacked above each other in an irregular	regularly scattered
	0	scattered	not scattered	scattered	not scattered
Distance between particles (10 pts.)	3		particles that have little empty spaces		particles that have little empty spaces
	2	particles close to each other	particles that have wide empty spaces	particles close to each other	particles that have wide empty spaces
	1	particles that are close to each other but	particles that have wide empty spaces	particles that are close to each other but	particles that have wide empty spaces
	0	particles that have wide empty spaces	particles that are close to each other	particles that have wide empty spaces	particles that are close to each other

Session 4: Reaction between sodium sulfide and hydrochloric acid

Full score: 39 points	Score	Na ₂ S (Ionic Crystal) represented as	HCl (Ions in Solution) represented as	H ₂ S (Gas) represented as	NaCl (Ions in Solution) represented as
VISUAL (20 pts.)					
Identity of the species (16 pts.)	5			molecule	
	4		discrete H ⁺ and Cl ⁻ ions	H ₂ diatomic molecule	discrete Na ⁺ and Cl ⁻ ions
	3	Na ⁺ and S ²⁻ ions	discrete H ⁺ and Cl ⁻ ions	discrete H and S atoms	discrete Na ⁺ and Cl ⁻ ions
	2	Na ⁺ and S ²⁻ ions	bonded H ⁺ and Cl ⁻ ions	bonded H and S ions	bonded Na ⁺ and Cl ⁻ ions
	1	Na ⁺ and S ²⁻ ions	discrete H and Cl atoms	H ₂ diatomic ion	discrete Na and Cl atoms
	0	molecule	HCl molecule	discrete H and S ions	NaCl molecule
Conservation of particles (4 pts.)	4	No. of Na, S, H and Cl particles before the reaction = No. of Na, S, H and Cl particles after the reaction as based on the balanced chemical equation			
	3	No. of particles of any 3 of the 4 species are equal before and after the reaction as based on the balanced chemical equation			
	2	No. of particles of any 2 of the 4 species are equal before and after the reaction as based on the balanced chemical equation			
	1	No. of particles of any 1 of the 4 species are equal before and after the reaction as based on the balanced chemical equation			
	0	No. of particles of all 4 species are not equal before and after the reaction as based on the balanced chemical equation			
SPATIAL (19 pts.)					
Arrangement of the particles (9 pts.)	3	alternating Na and S particles in a			
	2	alternating Na and S particles in an	irregularly scattered	irregularly scattered	irregularly scattered
	1	alternating columns or rows of Na and	regularly scattered	regularly scattered	regularly scattered
	0	scattered Na and S particles	not scattered	not scattered	not scattered
Distance between particles (10 pts.)	3		particles that have little empty spaces		particles that have little empty spaces between
	2	Na and S particles close to each other	particles that have wide empty spaces	particles that have wide empty spaces	particles that have wide empty spaces between
	1	particles close to each other but have little empty spaces	particles that have wide empty spaces between each other - comparable to (or more than) that of the H ₂ S gas	particles that have empty spaces between each other - comparable to that of HCl and NaCl solutions	particles that have wide empty spaces between each other - comparable to (or more than) that of the H ₂ S gas
	0	particles that have wide empty spaces	particles that are close to each other	particles that are close to each other	particles that are close to each other

Appendix K.2 Scoring Rubrics for the Transfer Test

Item 1 Hypothetical decomposition reaction

Full Score: 26 pts.	Score	A B (Liquid) represented as	A ₂ (Diatomic Gas) represented as	B ₂ (Diatomic Gas) represented as
VISUAL (13 pts.)				
Identity of the species (11 pts.)	5	molecule		
	4	A ₂ diatomic molecule and discrete B atom		
	3	discrete A and B atoms	diatomic molecule	diatomic molecule
	2	bonded A and B ions	discrete atom	discrete atom
	1	A ₂ diatomic ion and discrete B ion	diatomic ion	diatomic ion
	0	discrete A and B ions	discrete ion	discrete ion
Conservation of particles (2 pts.)	2	No. of A and B particles before the reaction = No. of A and B particles after the reaction as based on the balanced chemical equation		
	1	No. of A (or B) particles before the reaction = No. of A (or B) particles after the reaction as based on the balanced chemical equation		
	0	No. of A and B particles before the reaction ≠ No. of A and B particles after the reaction as based on the balanced chemical equation		
SPATIAL (13 pts.)				
Arrangement of the particles (6 pts.)	2	irregularly scattered	irregularly scattered	irregularly scattered
	1	regularly scattered	regularly scattered	regularly scattered
	0	not scattered	not scattered	not scattered
Distance between particles (7 pts.)	3	particles that have little empty spaces between each other		
	2	particles that have wide empty spaces between each other but less wide than A ₂ and B ₂ gases	particles that have empty spaces between each other and widely separated	particles that have empty spaces between each other and widely separated
	1	particles that have wide empty spaces between each other comparable to (or more than) that of A ₂ and B ₂ gases	particles that have empty spaces between each other comparable (or less) to that of liquid A B	particles that have empty spaces between each other comparable (or less) to that of liquid A B
	0	particles that are close to each other	particles that are close to each other	particles that are close to each other

Item 2: Double displacement reaction

Full Score: 39 points	Score	CaCl ₂ (Ions in Solution) represented as	KOH (Ions in Solution) represented as	Ca(OH) ₂ (Ionic Crystal) represented as	KCl (Ions in Solution) represented as
VISUAL (19 pts.)					
Identity of the species (15 pts.)	4	discrete Ca ²⁺ and Cl ⁻ ions	discrete K ⁺ and OH ⁻ ions		discrete K ⁺ and Cl ⁻ ions
	3	discrete Ca ²⁺ and Cl ²⁻ ions	discrete K ²⁺ and OH ²⁻ ions	Ca ²⁺ and OH ⁻ ions	discrete K ²⁺ and Cl ²⁻ ions
	2	bonded Ca ²⁺ and Cl ⁻ ions	bonded K ⁺ and OH ⁻ ions	Ca ²⁺ and OH ²⁻ ions	bonded K ⁺ and Cl ⁻ ions
	1	discrete Ca and Cl atoms	discrete K atom and OH molecule	Ca ²⁺ and OH ⁻ ions	discrete K and Cl atoms
	0	CaCl ₂ molecule	KOH molecule	molecule	KCl molecule
Conservation of particles (4 pts.)	4	No. of Ca, Cl, K and OH (O + H) particles before the reaction = No. of Ca, Cl, K and OH (O + H) particles after the reaction as based on the balanced chemical equation			
	3	No. of particles of any 3 of the 4 species are equal before and after the reaction as based on the balanced chemical equation			
	2	No. of particles of any 2 of the 4 species are equal before and after the reaction as based on the balanced chemical equation			
	1	No. of particles of any 1 of the 4 species are equal before and after the reaction as based on the balanced chemical equation			
	0	No. of particles of all 4 species are not equal before and after the reaction as based on the balanced chemical equation			
SPATIAL (20 pts.)					
Arrangement of the particles (9 pts.)	3			alternating Ca and OH particles in a regular way	
	2	irregularly scattered	irregularly scattered	alternating Ca and OH particles in an irregular way	irregularly scattered
	1	regularly scattered	regularly scattered	alternating columns or rows of Ca and OH particles	regularly scattered
	0	not scattered	not scattered	scattered Ca and OH particles	not scattered
Distance between particles (11 pts.)	3	particles that have little empty spaces between each other	particles that have little empty spaces between each other		particles that have little empty spaces between each other
	2	particles that have wide empty spaces between each other but not as wide as a gas	particles that have wide empty spaces between each other but not as wide as a gas	Ca and OH particles that are close to each other	particles that have wide empty spaces between each other but not as wide as a gas
	1	particles that have wide empty spaces between each other comparable to (or more than) that of a gas	particles that have wide empty spaces between each other comparable to (or more than) that of a gas	particles that are close to each other but have little empty spaces	particles that have wide empty spaces between each other comparable to (or more than) that of a gas
	0	particles that are close to each other	particles that are close to each other	particles that have wide empty spaces between each other	particles that are close to each other

Item 3: Combination reaction

Full score: 22 pts.	Score	Be (Metallic Crystal) represented as	O ₂ (Diatomic Gas) represented as	BeO (Ionic Crystal) represented as
VISUAL (9 pts.)				
Identity of the species (7 pts.)	3		diatomic molecule	Be ²⁺ and O ²⁻ ions
	2		discrete atom	Be and O ions
	1	atom	diatomic ion	Be ²⁺ and O ²⁻ ions
	0	ion	discrete ion	molecule
Conservation of particles (2 pts.)	2	No. of Be and O particles before the reaction = No. of Be and O particles after the reaction as based on the balanced chemical equation		
	1	No. of Be (or O) particles before the reaction = No. of Be (or O) particles after the reaction as based on the balanced chemical equation		
	0	No. of Be and O particles before the reaction ≠ No. of Be and O particles after the reaction as based on the balanced chemical equation		
SPATIAL (13 pts.)				
Arrangement of the particles (7 pts.)	3			alternating Be and O particles in a regular way
	2	stacked above each other in a regular way	irregularly scattered	alternating Be and O particles in an irregular way
	1	stacked above each other in an irregular way	regularly scattered	alternating columns or rows of Be and O particles
	0	scattered	not scattered	scattered Be and O particles
Distance between particles (6 pts.)	2	particles that close to each other	particles that have empty spaces between each other and are widely separated	particles that are close to each other
	1	particles that are close to each other but have little empty spaces	particles that have empty spaces between each other but not widely separated	particles that are close to each other but have little empty spaces
	0	particles that have wide empty spaces between each other	particles that are close to each other	particles that have wide empty spaces between each other

Item 4: Single replacement reaction

Full Score: 33 points	Score	Ca (Metallic Crystal) represented as	H ₂ SO ₄ (Ions in Solution) represented as	H ₂ (Diatomic Gas) represented as	CaSO ₄ (Ions in Solution) represented as
VISUAL (15 pts.)					
Identity of the species (12 pts.)	4		discrete H ⁺ and SO ₄ ²⁻ ions		discrete Ca ²⁺ and SO ₄ ²⁻ ions
	3		discrete H ₂ and SO ₄ ions	diatomic molecule	discrete Ca and SO ₄ ions
	2		bonded H and SO ₄ ions	discrete atom	bonded Ca and SO ₄ ions
	1	atom	discrete H atom and SO ₄ molecule	diatomic ion	discrete Ca atom and SO ₄ molecule
	0	ion	H ₂ SO ₄ molecule	discrete ion	CaSO ₄ molecule
Conservation of particles (3 pts.)	3	No. of Ca, H and SO ₄ (S + O) particles before the reaction = No. of Ca, H and SO ₄ (S + O) particles after the reaction as based on the balanced chemical equation			
	2	No. of particles of any 2 of the 3 species are equal before and after the reaction as based on the balanced chemical equation			
	1	No. of particles of any 1 of the 3 species are equal before and after the reaction as based on the balanced chemical equation			
	0	No. of particles of all 3 species are not equal before and after the reaction as based on the balanced chemical equation			
SPATIAL (18 pts.)					
Arrangement of the particles (8 pts.)	2	stacked above each other in a regular way	irregularly scattered	irregularly scattered	irregularly scattered
	1	stacked above each other in an irregular way	regularly scattered	regularly scattered	regularly scattered
	0	scattered	not scattered	not scattered	not scattered
Distance between particles (10 pts.)	3		particles that have little empty spaces between each other		particles that have little empty spaces between each other
	2	particles close to each other	particles that have wide empty spaces between each other but not as wide as a gas	particles that have empty spaces between each other and widely separated	particles that have wide empty spaces between each other but not as wide as a gas
	1	particles that are close to each other but have little empty spaces	particles that have wide empty spaces between each other comparable to (or more than) that of a gas	particles that have empty spaces between each other but not widely separated	particles that have wide empty spaces between each other comparable to (or more than) that of a gas
	0	particles that have wide empty spaces between each other	particles that are close to each other	particles that are close to each other	particles that are close to each other