EVALUATION OF THE MOLECULAR LEVEL VISUALISATION APPROACH FOR TEACHING AND LEARNING CHEMISTRY IN THAILAND

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DEDICATION

I dedicate this thesis to the memory of my father, Mr. Whane Phenglengdi.
ACKNOWLEDGMENTS

I give warm and sincere thanks to many people. My supervisor, Professor Roy Tasker, has to go first on the list. I thank Roy for his encouragement, assistance, and unflinching support. Roy met with me on countless occasions, and gave of his time graciously, even while transitioning to a new phase in his life in the United States. I still hope to work with Roy doing workshops in Thailand.

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My mom and dad have always been the true rock in my life. My dad was a life-long teacher, and had always hoped that I would obtain a PhD, and encouraged me to pursue that dream before he passed away. I thank my mom and dad for providing a stable, loving, and nurturing home without which I would not be here today.
I hereby declare that this submission is my own work, and that, to best of my knowledge and belief, it contains no material previously published by another person except where due acknowledgment is made in the text. This thesis contains no material that has been submitted or accepted for the award of any degree or diploma of a university or other institute of higher learning.

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## GLOSSARY

<table>
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<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Deep understanding</td>
<td>The ability to explain and describe substances and reactions at the molecular level and link these images to the observable and symbolic levels of thinking, and transfer this knowledge to everyday substances and processes</td>
</tr>
<tr>
<td>Mental model</td>
<td>The internal model that a student has to visualise the molecular level.</td>
</tr>
<tr>
<td>Molecular level visualisation approach</td>
<td>The VisChem seven-step learning design informed by an audio-visual information processing model, and consisting of observing, describing and explaining, discussing, viewing (animations used, along with pictures and diagrams), reflecting, relating and adapting.</td>
</tr>
<tr>
<td>Prior knowledge</td>
<td>The pre-existing knowledge, skills, beliefs and attitudes that students have when they come to the classroom.</td>
</tr>
<tr>
<td>Three levels of thinking</td>
<td>A categorization, first advanced by Alex Johnstone, that classifies scientific thinking at (1) the observable level (what we can see and touch); (2) the molecular level (the invisible world of molecules and ions), and (3) the symbolic level (the specialized language and notation of chemistry, and mathematics).</td>
</tr>
<tr>
<td><strong>Traditional approach</strong></td>
<td>A teaching method for chemistry predominantly using class lectures, worksheets and homework problems that focus on observable-level experiences explained using conventional notation—formulas and equations—at the symbolic level.</td>
</tr>
<tr>
<td>-------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>VisChem animation</strong></td>
<td>3D computer animations that portray the dynamic movement of molecules and ions, developed in the <em>VisChem</em> project.</td>
</tr>
</tbody>
</table>

ABSTRACT

This research evaluates the use of a molecular level visualisation approach in Thai secondary schools. The goal is to obtain insights about the usefulness of this approach, and to examine possible improvements in how the approach might be applied in the future.

The methodology used for this research used both qualitative and quantitative approaches. Data were collected in the form of pre- and post-intervention multiple choice questions, open-ended-questions, drawing exercises, one-to-one interviews and video recordings of class activity.

The research was conducted in two phases, involving a total of 261 students from the 11th Grade in Thailand. The use of VisChem animations in three studies was evaluated in Phase I. Study 1 was a pilot study exploring the benefits of incorporating VisChem animations to portray the molecular level. Study 2 compared test results between students exposed to these animations of molecular level events, and those not. Finally, in Study 3, test results were gathered from different types of schools (a rural school, a city school, and a university school). The results showed that students (and teachers) had misconceptions at the molecular level, and VisChem animations could help students understand chemistry concepts at the molecular level across all three types of schools. While the animation treatment group had a better score on the topic of states of water, the non-animation treatment group had a better score on the topic of dissolving sodium chloride in water than the animation group.

The molecular level visualisation approach as a learning design was evaluated in Phase II. This approach involved a combination of VisChem animations, pictures, and diagrams together with the seven-step VisChem learning design. The study involved three classes of students, each with a different treatment, described as Class A - Traditional approach; Class B - VisChem animations with traditional approach; and Class C - Molecular level visualisation approach. Pre-test and post-test scores were compared across the three classes.
The results from the multiple choice and calculation tests showed that the *Class C – molecular level visualisation approach* group demonstrated a deeper understanding of chemistry concepts than students in Classes A and B. However, the results showed that all the students were unable to perform satisfactorily on the calculation tests because the students had insufficient prior knowledge about stoichiometry to connect with the new knowledge.

In the drawing tests the students exposed to the molecular level visualisation approach had a better mental model than the other classes, albeit with some remaining misconceptions. The findings highlight the intersecting nature of the teacher, student, and modelling in chemistry teaching.

Use of a multi-step molecular level visualisation approach that encourages observation, reflection of prior understanding, and multiple opportunities at viewing (and using various visualisation elements), are key elements leading to a deeper understanding of chemistry. Presentation of the multi-step molecular level visualisation approach must be coupled with careful consideration of student prior knowledge, and with adequate guidance from a teacher who understands the topics at a deep level.
CHAPTER 1
INTRODUCTION

This thesis examines a problem that has plagued chemistry teachers for some time: how to illuminate the workings of the unseen molecular world to students, and how to help students achieve a deeper understanding of these workings.

The particular statement of the problem, research aims, research questions, significance of the research, and the research outline are outlined below. The impetus for this research stems from the researcher’s experience as a student of chemistry in Thailand, and subsequent experience as a chemistry teacher in Thailand.

1.1 Introduction

The question presented is whether teaching and learning of chemistry could be improved by incorporation of animations as part of a broader multi-modal teaching design. Overall, “[t]here has been little Thai-based research of student understanding of chemistry teaching and learning” (Dahsah & Coll, 2007, p. 578). The particular question posed is whether molecular level visualisation techniques can help students achieve a deeper understanding of chemistry either standing alone, or incorporated as a part of a broader teaching design.

The setting for this research is Thailand. Visualisation techniques are not often used in Thai classrooms. Indeed, teaching tends to focus primarily on the symbolic level of chemistry teaching. The focus on symbolic level teaching is not surprising: teachers seek to obtain positive student pass rates on college entrance examinations, and those examinations have not changed or evolved in response to educational reform (Coll, Dahsah, & Faikhamta, 2010a). The examinations reward
numerical problem solving rather than rewarding a display of deep understanding in chemistry (Dahsah & Coll, 2007).

The problem of achieving a deep understanding in chemistry stems, in part, from the difference between what we might observe day-to-day, and what is happening at the molecular level that we cannot see. We have all experienced basic chemical reactions in our day to day life, but do not necessarily understand what is happening at the molecular level. From an early age, we observe that when we are cooking and add salt in food, the salt dissolved. The salt no longer existed in a solid state, but changed to be an aqueous solution. These everyday reactions can shape preliminary, incorrect conceptions about chemistry. Indeed, by the time students are introduced to particle theory during secondary school, the students may try to relate particle behavior to the macroscopic properties of matter the students have observed (Adadan, 2013).

Visualisation based approaches hold promise in part because they may assist students in developing appropriate mental models at the molecular level. As will be discussed in Chapter Two, Johnstone (1982) introduced the idea of three thinking levels which included the molecular level as well as the macroscopic (observable) and the symbolic levels. To understand scientific knowledge, the students must be able to understand the knowledge at the three levels, and must be able to understand the role and relationships between the three levels (Jansoon, Coll & Somsook, 2009). Prior research in Thailand supports the idea that teaching is too focused on the symbolic level, and students have difficulty connecting the symbolic and observable levels to the molecular level (Jansoon et al., 2009; Kuathan, Faikhamta & Sanguanruang, 2011). Revealing the molecular level complements what the students observe (macroscopic), and what they might be taught about chemistry formulas or equations (symbolic). Ultimately, those students who are better able to understand the relationship of the representations in the three levels display a better understanding than those students who do not (Jansoon et al., 2009).
1.2 Rationale for Study

The primary impetus for this study stems from the proposition that chemistry teaching and learning could be improved in Thailand secondary schools by focusing on discrete adjustments to chemistry teaching methods. To that end, various chemistry classes were observed—in various settings—and using various teaching techniques.

Actual classroom instruction is the focus of this study, not teaching theory or learning theory. However, as classroom teaching is the focus of this study, both teachers and students are—directly or indirectly—being observed and analysed during the course of this research.

Teachers are a primary focus point. By observing how teaching actually occurs, a “baseline” is set that we refer to as the traditional teaching. The traditional teaching—once defined by and through observation of secondary-school chemistry teaching in Thailand—can then be compared to other teaching methods. Here, for example, we incorporate animations, and then separately implement a seven-step teaching design using animations and static displays.

Comparison of approaches relies, in this thesis, on input from students. Student participation includes testing and interviews. Subjective perceptions of the various teaching methods, when combined with the actual results from interviews and testing, provides a valuable data set from which conclusions can be drawn about the usefulness or desirability of implementing a seven-step molecular level visualisation approach.

Two overarching issues provide justification for research about Thai chemistry teaching: (1) a documented low performance of Thai students in relative terms to other nations; (2) long-standing practices in Thai classrooms focusing on symbolic level equations and problem solving for purposes of testing. This study observes first-hand the chemistry instruction in Thailand. The researcher posits that the molecular level visualisation approach should be a central component to the secondary school syllabus. Incorporating a molecular level visualisation approach
can help provide a solid lesson plan for teachers (sample lesson plan included in Chapter 6), while providing students with a deeper, richer understanding of chemistry and, this researcher contends, better test performance and understanding—at a deep level—of the underlying chemistry concepts.

1.3 Statement of the Problem

Chemistry teaching implicates questions both about national priorities and goals, as well as classroom level best practices. At the national level, Thailand is still undergoing academic reform, and that academic reform raises basic questions about social priorities and social justice. These issues, while significant and worthy of independent research, are not the focus of this research, but are noted briefly below.

This research focuses on the classroom: the teacher, the students, and the methods used to teach. The need for this research can be demonstrated in four ways: (1) national goals exist to reform science education and teaching of science, but the goals remain largely unfulfilled; (2) poor student performance in Thailand was documented during monitoring by the Programme for International Student Assessment (PISA) and Trends in Mathematics and Science Study (TIMSS). The poor student performance was accompanied by a precipitous fall in student performance relating to science and technology education as marked by indicators reported by the International Institute for Management Development (IMD) (Dahsah & Coll, 2007); (3) current stagnation in how chemistry is taught in Thailand; (4) while numerous articles have identified a need for changes in chemistry teaching and focusing on the “three levels of thinking,” little research has been conducted about the actual benefits of a three-thinking-levels approach, or student responses to such an approach.

1.3.1 Thailand Educational Reform and Priorities

The need for improvements in Thai classroom teaching, and in the area of science in particular, has received broad national support in Thailand. Considering improvements to science teaching is not merely academic. Scientific literacy implicates important international and intranational considerations (Dahsah & Coll,
A populous well versed in science may act as an engine for economic development, for example (Dahsah & Coll, 2007). Nineteen percent of Thailand’s income inequality, meanwhile, is said to stem from disparities in education (World Bank, 2006).

To some extent, efforts at reform have stemmed from the realisation that education can impact Thailand’s national well-being. Recent educational reform efforts in Thailand have resulted from the pressures of globalisation and the Asian economic crises of 1997 (UNESCO, 2011). A major impetus for educational reform has been to try and shield the economy from future economic shocks (Coll et al, 2010a).

Major elements for education reform as articulated in the National Education Act of 1999 and 2002 include among them the following:

- Shifting from teacher-centred to student-centred learning
- Better use of technology to promote learning

Development of science and technology, and related research and development, has been articulated as a current goal of educational reform in Thailand (UNESCO, 2011).

The goals of educational reform have fallen short in the implementation. According to one study, less than half of students held a “sound understanding” related to the topics of secondary school level chemistry like atomic mass, molar mass of compound, solution and chemical reactions (Dahsah & Coll, 2007). Despite educational reform goals, the teaching is still not learner-centred, and no genuine commitment exists to move towards a learner-centred curriculum (Coll et al., 2010a). School quality in Thailand has been likened to “‘being in a coma,’” and as of 2008 less than half of schools met a “good” standard” (UNESCO, 2011, p. 33). There is still too heavy an emphasis on symbolic level equations and testing (Jansoon et al., 2009). University entrance examinations that reward “rote learning” acts as a disincentive to modify current chemistry teaching methods (Coll, Jansoon, Dahsah & Chairam, 2010b, p. 218; Dahsah & Coll, 2007, p. 596).
1.3.2 Documented Poor Student Performance

Student performance in Thailand on science topics has been well documented, and points to an existing problem which needs to be addressed (UNESCO, 2011). The overall trend is that student performance in science has not been satisfactory (Coll et al., 2010a).

The National Institute of Educational Testing Service (NIETS) confirmed low academic proficiency of Thai students in the sciences. The NIETS conducts Ordinary National Educational Test (O-NET) for students in Grades 6, 9 and 12. The main purposes of NIETS are to assess student academic proficiency, and to provide information to the schools to evaluate the quality of eight major subject areas based on the national Education Curriculum, namely: Thai Language, Mathematics, Science, Social Science, Religion and Culture, Health and Physical Education, Art, Career and Technology, and Foreign Languages (NIETS, 2012). Results from the Ordinary National Educational Test (O-NET) show that Thai students from Grade 12 have a low score in science compared to most other subjects (Table 1.1) (NIETS, 2012) (cf. English and mathematics that had an even lower score).

Table 1.1

*Comparison of the average score with percentage of the Ordinary National Educational Test (O-NET) among eight subjects in Thailand from grade 12 in 2009*

<table>
<thead>
<tr>
<th>Subject</th>
<th>Mean Score (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thai Language</td>
<td>46.47</td>
</tr>
<tr>
<td>Social Science, Religion and Culture</td>
<td>36.00</td>
</tr>
<tr>
<td>English</td>
<td>23.98</td>
</tr>
<tr>
<td>Mathematics</td>
<td>28.56</td>
</tr>
<tr>
<td>Science</td>
<td><strong>29.05</strong></td>
</tr>
<tr>
<td>Health and Physical Education</td>
<td>45.37</td>
</tr>
<tr>
<td>Art</td>
<td>37.75</td>
</tr>
<tr>
<td>Career and Technology</td>
<td>32.98</td>
</tr>
</tbody>
</table>
These findings are also confirmed by the Program for International Student Assessment (PISA) (OECD, 2014). The PISA is an international assessment that measures 15-year-old students' reading, mathematics, and science literacy. PISA is coordinated by the Organisation for Economic Cooperation and Development (OECD), an intergovernmental organisation of industrialised countries. The PISA assessment was first administered in 2000 and is conducted every three years. The result from PISA in 2012 showed Thai students have a low science score compared to other countries, and the result is lower than the OECD average score (see Table 1.2)

Table 1.2

*Comparison of the science scores for Grade 12 of the PISA 2012 database*

<table>
<thead>
<tr>
<th>Countries</th>
<th>Science Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shanghai-China</td>
<td>580</td>
</tr>
<tr>
<td>Singapore</td>
<td>551</td>
</tr>
<tr>
<td>Japan</td>
<td>547</td>
</tr>
<tr>
<td>Finland</td>
<td>545</td>
</tr>
<tr>
<td>Korea</td>
<td>538</td>
</tr>
<tr>
<td>Australia</td>
<td>521</td>
</tr>
<tr>
<td>United states</td>
<td>497</td>
</tr>
<tr>
<td>OECD average score</td>
<td>501*</td>
</tr>
<tr>
<td>Thailand</td>
<td>444</td>
</tr>
<tr>
<td>Indonesia</td>
<td>382</td>
</tr>
</tbody>
</table>

Note: The results are from selected countries, Source. PISA 2012 database

1.3.3 Real World Experience of Learning and Teaching Chemistry in Thailand

The researcher’s experiences of learning and teaching chemistry in Thailand tend to confirm concerns about Thai student performance in sciences, and chemistry
in specific. Those experiences span being a high school student in the Surin Province of Thailand, continuing with university studies in chemistry, and ultimately becoming a teacher of chemistry. The chemistry teaching was consistently teacher centred, primarily based on lectures supported by a textbook, pictures, static displays, laboratory experiments and symbolic level questions or testing. Some of the real world experiences of teaching and learning chemistry in Thailand are summarised below:

*Stage One:* High School Student, Grades 10-12 (1991-1993)

Chemistry teaching during high school years involved the following elements: 1) Teachers taught using an explanation style; teachers were always in front of the class (teacher centred); 2) Few laboratory experiments were conducted; 3) The class never viewed computer visual representations, but instead used only pictures from textbooks; 4) Teaching focused on passing university examination; 5) The molecular level of chemistry was not a commonly taught or emphasized part of the learning experience.

*Stage Two:* University Student, Major: Chemistry Education (1994-1997)

The experience of learning chemistry at the university level was similar to high school years, with the exception of increased laboratory experiments and occasional use of ball and stick figures.

*Stage Three:* Chemistry Teacher (1998-2005)

As a chemistry teacher, my methods mirrored how I was taught. Teaching remained teacher centred, and the focus was on preparing students to pass university examinations. The molecular level was not a focus of the teaching.

The experiences described above are confirmed by other researchers. Thai classroom teaching has been described as “teacher-dominated,” and following a “cookbook style” (Coll et al., 2010b, p. 211). Test results during other research where students had to not only answer, but then describe their answers, suggested that memorisation of concepts was favoured over learning the details of chemistry instruction (Dahsah & Coll, 2007). Researchers have concluded that the focus of chemistry teaching in Thailand should shift from a symbolic-level-dominated
instructional method, to teaching explicitly requiring students to think about and relate the three levels to each other (Jansoon et al., 2009).

1.3.4 Limited Analysis of Animations in the Thai Classroom Exist

Research in Thailand about using animations for chemistry teaching is limited. The potential benefit of animations is that they can reveal the workings of the otherwise unviewable microscopic world. That microscopic world is multiparticulate and dynamic. While many ways of representing that unseen world have been tried, including drawings, role-play as “particles,” or using physical models, better conceptual understanding has been obtained by using animations (Williamson, Lane, Gilbreath, Tasker, Ashkenazi, Williamson & MacFarlane, 2012). Indeed, animations would appear to hold the most promise for helping students construct and apply useful mental models of the microscopic world (Jones, Honts, Tasker, Tversky, Suits, Falvo, & Kelly, 2011).

Research in northeast Thailand demonstrated that at least some teachers were interested in incorporating animations. The teachers who were interviewed acknowledged the general difficulty of teaching abstract topics in chemistry (Chomchid, Inyega & Thomson, 2009). The teachers described the abstract topics of chemistry as being difficult, or very difficult, to teach (Chomchid et al., 2009). The teachers also acknowledged the difficulty of constructing their own instructional materials for these topics, and expressed a desire to use computer assisted visual teaching (Chomchid et al., 2009).

With specific reference to teaching atomic structures and periodic tables, Thai teachers cited lack of concrete teaching materials, and student basic knowledge and skills, as two of the problems most frequently encountered (Chomchid et al., 2009). The need in general for more effective teaching strategies of secondary school level chemical topics in Thailand has also been recognised (Chaiyen, Bunsawansong, & Yutakom, 2007). Strategies such as modifying laboratory work to better meet the needs of students and teachers have also been examined (Techakosit & Jeerangsuan, 2013). Cumulatively, the research points to a genuine interest in modifying classroom methods to better meet students’ educational needs.
Some limited research in Thailand exists about incorporating animations at the college level. In one college level study, animations were specifically developed for a college level Nuclear Magnetic Resonance (NMR) spectroscopy course, along with interactive exercises or problem sets (Supasorn & Vibuljan, 2009). The results generally showed improvement in test results, and positive feedback from the students. While the test results were helpful, questions about deep level understanding, or questions or problems specific to secondary school level students, were not addressed. Similarly, 3D animations were presented in a college level organic chemistry course, with the results focusing in large part on positive student reactions, and noting an enthusiastic atmosphere in the classroom (Khantikaew, Kuppithayanant, Tantivong & Kaewchoay, 2005).

In summary, while some research about chemistry teaching and use of animations in Thailand exists, that research primarily focuses on the need or potential for classroom teaching method changes. That need or potential requires a more rigorous analysis.

1.4 Significance of the Research

This research fills what appears to be a remaining gap in Thai secondary school curricula: improving the teaching of chemistry to use all three levels of thinking (observable, molecular, symbolic), through a constructivist, learner-centred approach incorporating animations. Researchers have called out for new teaching approaches in Thailand that provide increased emphasis on all thinking levels in chemistry (Jansoon et al., 2009), but exactly how to so implement such a new approach remains undetermined.

This research focuses on one concrete, potential way to improve chemistry teaching: using animations as part of a molecular level visualisation approach. As used in this research, animations are a kind of dynamic, computer-generated graphic, and a molecular level visualisation approach is a seven-step method of teaching that incorporates animations and other visual representations in the classroom. Adopting animations, and use of a molecular level visualisation approach, could also advance
the national educational goals of being learner-centred and making better use of technology (UNESCO, 2011).

This research may act as an impetus for change in how chemistry teaching is performed. The results of this research may make Thai teachers feel more confident implementing a molecular level visualisation approach. Thailand chemistry teaching is currently dominated by “traditional” teaching methods: lectures, worksheets and homework problems that focus on using conventional symbolism—formulas and equations—at the symbolic level. The teachers usually focus on coaching students in solving numerical problems common to university examinations. Achieving a deeper understanding of the underlying science concepts is not a common teaching goal. Highlighting the benefits of a different approach may change the classroom dynamic, and shift instruction to a student-centred approach. Interest in change exists as demonstrated in one study where teachers’ top request was to use animations to teach atomic structures and periodic tables (Chomchid et al., 2009).

This research also may directly benefit Thai students. Thai students have misconceptions in chemistry in part because most students have difficulties imagining the molecular level of substances (Coll et al., 2010b). The results of this research support the idea that applying a multi-step, three-levels-of-thinking approach that incorporates animations (here via a molecular level visualisation approach) can indeed lead to a deeper understanding of chemistry. Researchers have already noted the relative enthusiasm students expressed for using animations when they are offered (Khantikaew et al., 2005).

The data collected here ultimately makes the theoretical discussions about modifying teaching techniques more concrete: can animations and a molecular level visualisation approach that incorporates animations improve deep understanding compared to traditional approach?

Data about teaching and learning were collected through observations of in-class instruction, multiple choice testing, drawings, calculations, and interviews with students and teachers. Tests were administered before and after teaching, and follow-up interviews were conducted by the researcher. This data can be used to
identify misconceptions that Thai students have, and can be used to identify how teaching might be modified to lead to a deeper understanding of secondary school chemistry topics. The teaching and learning principles developed here may help to reform the education system in Thailand and, in so doing, may benefit teachers and students alike.

1.5 Research Aims

The primary research aim is to evaluate the molecular level visualisation approach for teaching and learning chemistry in Thai secondary schools. The research study was designed to achieve the three following research aims:

1) To evaluate the use of VisChem animations in the Thai secondary school context;
2) To evaluate the molecular level visualisation approach;
3) To promote Thai secondary school students’ deep understanding in chemistry.

1.6 Research Questions

This research was divided into two phases. Phase I was used to explore teaching and learning chemistry using VisChem animations. This phase consisted of three studies. Study 1 was a pilot study applying the animations. Study 2 compared results in a class using animations with a class using a traditional approach. Study 3 used the animations in three schools located in different geographical parts of Thailand (university, city and rural schools).

The animation used in this research is a VisChem animation (http://www.vischem.com.au). The VisChem animation is designed by Professor Roy Tasker (UWS) in collaboration with Bob Bucat (UWA), Ray Sleet (UTS), and Bill Chia (UWS).

Phase II was used to evaluate the molecular level visualisation approach and to compare results with other classes taught either with a traditional approach, or
with a traditional approach that incorporated animations. The research questions for Phase I and Phase II are noted below.

Phase I: Exploration of Use and Effectiveness of VisChem Animations

Study 1: Pilot Study
1. How do teachers teach and students learn when using the animations?
2. Do animations help students better understand the molecular level?
3. How do students’ mental models change after using animations?

Study 2: Comparison of Groups
1. How do teachers teach and students learn when using the animations and when not using the animations?
2. Do the animations help students better understand the molecular level compared to the non-animation group?
3. How do students’ mental models change after using animations?

Study 3: Application of VisChem animations in Three Different Schools
1. Do the animations help students in each school better understand the molecular level?
2. How do students’ mental models change in each school after using animations?

Phase II: Implementation of the Molecular Level Visualisation Approach

The primary purpose of Phase II was to evaluate the molecular level visualisation approach and to compare results with classrooms taught by either traditional methods, or by traditional methods that used animations. The questions for each of the three classrooms are similar, with the goal of comparing results:
1. How do teachers teach and students learn chemistry?
2. Does the particular approach (depending on the one used) help students deep understand in chemistry?
3. How do students’ mental models change?
4. How do the three classrooms compare when examining their deep understanding of the topics?
1.7 Research Design

Mixed methods were applied to collect and analyse data in this research study. Both qualitative and quantitative mechanisms were used, including multiple choice tests, drawings, calculations, observation of classrooms, and interviews. The participants were 261 Grade 11 students, mixed gender, all around 16-18 years old. A total of six chemistry teachers participated. The data was collected in Thailand from 2012 (Phase I) and 2014 (Phase II) (see Figure 1.1).

**Figure 1.1. Research design**

1.8 Research Outline

Chapter Two of this thesis will provide an overview of literature relating to animations (graphic computer generated representations) and the VisChem learning design. The cognitive learning model will be discussed. Basic conceptual framework issues relating to deep understanding, the three levels of thinking in chemistry, and common misconceptions in chemistry will also be analysed.

Research relating to use of visualisations (i.e., animations, static displays, or other visual guides) and modelling, and the basis for applying a multi-step molecular level visualisation learning design will be addressed. Chapter 3 provides an overview of the mixed method methodology used in this research, as well as addressing issues of ethics and trustworthiness. The particulars of the research design, and details of this
research study including data collection techniques and data analysis in each phase will be described.

Chapters 4 and 5 will provide detail about the results and findings of the research. The results and findings for when animations are incorporated in the classroom are discussed in Chapter 4. Chapter 5, meanwhile, sets forth the results from applying the molecular level visualisation approach.

Chapter 6 summarises and discusses the key points from the data obtained in Phases I and II, and makes recommendations for further research. Ultimately, the data derived from this research support the use of a molecular level visualisation approach to teaching chemistry at the molecular level.
CHAPTER 2

LITERATURE REVIEW

This research explores whether applying a multi-step molecular level visualisation approach incorporating animations results in a deeper understanding of chemistry concepts. To answer this question, research was performed in Thai classrooms examining how teachers teach, and what improvements, if any, could be made. The research was conducted in two phases. During the first phase, animations were used in variety of classroom settings. During the second phase, a multi-step molecular level visualisation approach was used, a portion of which included the use of animations. Results were compared to two classes not using the molecular level visualisation approach.

The molecular level visualisation approach takes it origins from an informational processing model, and incorporates animations and various visualisation elements. The visualisation approach builds on several relevant strands of chemistry research and educational theory. That research and educational theory will be discussed in this chapter. Sections 2.1 through 2.6 are briefly outlined below, followed by a more detailed discussion.

Section 2.1 The Three Thinking Levels

The foundation for this research draws on the work of Alex Johnstone (1991) and his paradigmatic three levels of thinking in chemistry. The three levels of thinking frames the “why” for difficulties in teaching chemistry.

Section 2.2 Misconceptions in Chemistry

The existence of misconceptions or misunderstandings in chemistry at the molecular level is a basic assumption of this thesis. Improving instruction requires an acknowledgment of what problems exist. A summary of research about misconceptions in chemistry is provided.
Section 2.3 Information Processing Model

The information processing model describes how learning occurs, and the elements involved such as filtering, short term memory, and long term memory.

Section 2.4 VisChem Learning Design

The *VisChem* (Visualising Chemistry) learning design is informed by the information processing model, and related research, to create a seven step sequence of suggested learning activities. The *VisChem* learning design will be examined, and explained, with reference to relevant educational models or theories.

Section 2.5 Visual Representations

This research concludes that no single visualisation method is necessarily appropriate, but that multiple visualisations can, and should, be used in the classroom. Research related to animations and visualisations will be discussed.

Section 2.6 Deep Understanding

A basic goal of this thesis is to determine whether understanding of chemistry concepts can be improved by adoption of a visualisation approach. Understanding as used in this research means “deep understanding.” What is meant by “deep understanding” is explained in this section.

The multiple choice tests, and open-ended questions and drawings, and interviews were all carefully developed to probe understanding at a deep level, as explained in Chapter 3.

### 2.1 Three Levels of Thinking

Student difficulty in understanding chemistry occurs at all levels of education (De Berg, 2012). Johnstone (1991) tackled the question of why science topics are hard to learn. Among other reasons for why science topics are hard to learn, Johnstone noted that much of what happens occurs with no readily available sensory way to understand the event: concepts like electron, bond energy, or molecules are matters left to a person’s imagination (Johnstone, 1991). Those concepts that are beyond our ability to view directly are interpreted in relationship to the macroscopic world—what we can see—and the symbolic world—the language of symbols. Chemistry teaching blends these multi-levels of understanding without necessarily appreciating the demands being placed on the students to understand, and synthesise,
this information across the various levels (Johnstone, 1991). Student misunderstandings about the multi-level relationships manifest as misconceptions on a wide range of chemistry topics (Levy Nahum, Hofstein, Mamlok-Naaman & Bar-Dov, 2004; Nakiboglu, 2003; Taber, 1994, 2002a)

The difficulties identified by Johnstone—lack of sensory experience of certain science subjects, and multi-level thinking—can be discussed with reference to the triangle of thinking levels. The three thinking-levels on a triangle (Figure 2.1) include the *macro* (referred to here as the *observable* level), the *sub-micro* (referred to here as the *molecular* level), and the *representational* (referred to here as the *symbolic* level). Chemistry ideas are taught and communicated at these levels. The three levels are considered to be paradigmatic in current chemistry teaching (Talanquer, 2011).

![Figure 2.1. The three thinking-level model (Johnstone, 1991)](image)

**The Observable Level.** The observable level involves the things that we can see, touch or smell, including doing experiments inside or outside the classroom. For example, students can observe water in a beaker; they can see the water with their naked eyes; they can explain the water at this level (it is a colourless). However, it is very difficult to explain the particles of water at the molecular level because the particles are invisible, and therefore abstract.

**The Molecular Level.** The molecular level involves things that we cannot see, such as atoms, ions or molecules. Students taught using a traditional teaching approach have to construct or imagine their own mental models of atoms, ions, or molecules. Many students have misconceptions in this level because the level is dynamic, not static, and is invisible, and thus hard to imagine and to understand.
Student misconceptions in the molecular level are common, and the misconceptions are described in detail in Section 2.2.2. Fortunately, many kinds of models and visual representations have been developed to help students understand the molecular level. The types of visual representations are explained in Section 2.5.

**Symbolic Level.** The symbolic level involves portraying molecules, atoms, ions, substances, and physical and chemical changes using symbols, chemical equations and mathematics. We use the equations or formulas to represent phenomena at the observable level, and particles at the molecular level. For example, the chemical formula H₂O can represent one water molecule, or the liquid substance water if followed by “(l)”. This level generates many misconceptions due to confusion over what is being conveyed. For example, does HCl indicate aqueous hydrochloric acid solution (no HCl molecules exist in this solution), or the HCl molecule? This part is still invisible for students, so teachers have to approach the topic carefully to allow linking of the three levels.

Tasker and Dalton (2006) used the following diagram to illustrate the three levels of thinking about a particular reaction (see Figure 2.2):

![Figure 2.2. A reaction at chemical equilibrium portrayed at the three thinking levels](image)

Students are often unable to see the linkages between the three levels although they may know chemistry exists at the three levels (Tasker & Dalton, 2006). For improved conceptual understanding, it is important to help students see the threefold relationship (Gabel, 1999).
Students able to understand the three levels of thinking generally display a better understanding of chemistry. Jansoon et al. (2009) observed that students who understand the role of the three levels can transfer knowledge from one level to another, and can generate relational understanding. In reaching that conclusion, they examined how first year university students tried to explain dilution and related topics. Data was collected by open-ended questions, drawings and descriptions, and interviews. Although all students were able to answer questions about dilution, a notable difference existed between high ability and low ability students. Specifically, high ability students were able to describe their answers at all three levels, whereas low ability students were only able to answer questions at the symbolic level, and their answers at the macroscopic or molecular level were not necessarily related.

Further support for using the three levels of thinking approach comes from research by Bunce and Gabel (2002). That research compared teaching and learning approaches between a treatment group using three levels of thinking, and a control group using only two levels (macroscopic and symbolic levels). Data were collected from various high school students. After two weeks of teaching and learning, the treatment group scored significantly higher than the control group as measured by a comparison of achievements tests used for each of three classroom modules. The results suggest that teaching and learning with all three levels of thinking can help students achieve a better understanding in chemistry.

Although the benefits of using three levels of thinking for teaching and learning chemistry seems well recognised, many chemistry teachers still teach students using only the symbolic level, or sometimes using the symbolic and the laboratory level. The molecular level is often lacking in the classroom because it is very hard to present the associated ideas (Gabel, 1999). Many high school teachers do not expressly integrate the three representations in their teaching but, instead, move between representations without saying how each is related to the other (Gabel, 1999).

Focusing only on the symbolic and the observable levels has been shown to lead to problems with student understanding (Johnstone, 1993; Nakhleh, 1992).
Johnstone (1993) indicated that one reason that students have difficulty learning chemistry is that they do not understand the relationships between the levels, especially when teachers use the symbolic level without building connections to the other levels. Linking can occur when teachers present at the observable level where students can then see, touch or observe the phenomenon, and then move to the molecular level by using the visual representations such as pictures, diagrams or computer animations (see Figure 2.2).

Student misconceptions in chemistry have, by this time, been well documented. Nakhleh (1992) identified various chemistry misconceptions held by secondary school and university level students. Students at all levels held “profound misconceptions” regarding the particulate and kinetic nature of matter, and many students held a static, rather than a kinetic, view of the particulate model of matter (Nakhleh, 1992, pp. 193, 195). The author pointed out that an appropriate understanding of matter being composed of atoms, molecules and ions, and their kinetic aspects, is the foundation for understanding basic chemical concepts. The author recommended increased focus on helping students to understand these concepts. Students need to be able to see connections between the equations that they write and the submicroscopic nature of the equations (Kelly, Barrera, & Mohamed, 2010). These student misconceptions in chemistry are described in more detail below.

2.2 Misconceptions in Chemistry

Nakhleh’s (1992) findings about student misconceptions in chemistry are confirmed in a broad range of other research, which will be briefly discussed and then summarised below. The misconceptions confirm a fundamental problem with student understanding at the molecular level.

2.2.1 Use of Term “Misconception”

Before examining the particular misconceptions held by students of chemistry, some discussion is required about how to refer to student responses and whether, indeed, “misconception” is an appropriate term to apply.
A researcher’s choice of terminology gives insight into their epistemological views. Nakhleh (1992, p. 191), defines a misconception as “any concept that differs from the commonly-accepted scientific understanding of the term.” Hallden, Petersson, Scheja, Ehrlen, Haglund, Osterlind and Stenlund (2002) use the term "alternative conception" showing their belief in a situated epistemology: in this view, some consideration must be given to the particular viewpoint of the person. Sneider and Ohadi (1998, p. 266 n.1), meanwhile, prefer “to retain the original term ‘misconception,’” rather than, for example, “preconception” or “naïve theory” because the term “misconception” emphasises the goal of helping students “construct for themselves a logical theory … that is in agreement with modern science.” Researchers like Artdej, Ratanaroutai, Coll and Thongpanchang (2010) use "alternative conception," and researchers like Naah and Sanger (2012) use "misconception."

In this thesis, the term "misconception" will be used to refer to student understandings that do not conform to generally accept scientific understandings. Using the term “misconception” is not intended to disrespect the viewpoint of individual students, but still recognises that certain conceptions are inconsistent with generally accepted scientific principles.

**2.2.2 Summary of Commonly held Misconceptions**

The difficulty of teaching or learning chemistry is that the underlying concepts centre on the molecular level (Badrian, Abdinejad & Naseriazar, 2011; Levy Nahum, Mamlok-Naaman, Hofstein & Taber, 2010; Tasker & Dalton, 2008). Misconceptions at the molecular level are described below.

Boz (2006) confirmed difficulties understanding the molecular level for 13, 15, and 17 year old students in Turkey. Boz investigated Turkish students’ views about the particulate nature of matter within the context of phase change. The researcher used semi-structured interviews and open-ended questions about 1) the arrangement and movement of particles in a solid, liquid and gas, and 2) the application of particle ideas to explain phase changes. Approximately 300 students participated in the research. Many students had difficulty using the particulate theory
to explain phase changes. For example, students had misconceptions with the degree of movement of particles in a solid substance. In the solid state, particles vibrate in fixed positions. But students thought that particles in the solid state remain static. The reason for the student understanding may be that a solid substance has a fixed shape, and particles are very close to each other. The study recommended using models or computer simulations to explain the molecular level and to prevent the misconception, and recommended that the teacher explain the differences between the observable level and the molecular level.

Tasker and Dalton (2006) described how students have difficulty understanding chemistry because the students cannot see particles in the abstract world. They found that many students had difficulty imagining the arrangement of water molecules in a liquid state, and they could not imagine the arrangement of the particles in an aqueous sodium chloride solution. Indeed, as shown in Table 2.1, most chemistry misconceptions exist in the abstract part of chemistry.

Kelly et al. (2010) also explored the nature of molecular level understandings as shown in student drawings and explanations. The findings indicated that students are unclear about the definition of an aqueous solution and about the nature of ionic compounds. Many students seemed confused about the workings of the molecular level if the instruction tended to use only symbolic and macroscopic levels.

Other researchers have confirmed a broad range of misconceptions in chemistry, especially misconceptions at the molecular level (see Table 2.1).

Table 2.1

<table>
<thead>
<tr>
<th>Misconception/difficulty</th>
<th>References</th>
<th>Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students incorrectly believe that atoms and molecules have macroscopic properties, e.g., they expand when a substance is heated</td>
<td>Yakmaci –Guzel (2013)</td>
<td>Pre service chemistry teachers</td>
</tr>
<tr>
<td></td>
<td>Stojanovska et al. (2012)</td>
<td>High school and secondary school</td>
</tr>
<tr>
<td></td>
<td>Badrian et al. (2011)</td>
<td>Years 9-11</td>
</tr>
<tr>
<td>Misconception/difficulty</td>
<td>References</td>
<td>Participants</td>
</tr>
<tr>
<td>--------------------------------------------------------------</td>
<td>----------------------------------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>Students often find the process by which ionic compounds</td>
<td>Naah and Sanger (2012)</td>
<td>College students</td>
</tr>
<tr>
<td>dissolve in water abstract and difficult to understand</td>
<td>Liu and Lesniak (2006)</td>
<td>Elementary to high school</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Students confuse the dissolving process with melting</td>
<td>Smith and Nakhleh (2011)</td>
<td>University students</td>
</tr>
<tr>
<td></td>
<td>Tien et al. (2007)</td>
<td>College and university students</td>
</tr>
<tr>
<td></td>
<td>Liu and Lesniak (2006)</td>
<td>Elementary to high school</td>
</tr>
<tr>
<td></td>
<td>Boz (2006)</td>
<td>Years 6, 8, 11</td>
</tr>
<tr>
<td></td>
<td>Ebenzer and Gaskell (1995)</td>
<td>Year 11</td>
</tr>
<tr>
<td></td>
<td>Haidar and Abraham (1991)</td>
<td>Years 11 and 12</td>
</tr>
<tr>
<td>The dissolved compound reacting or bonding with water</td>
<td>Naah and Sanger (2012)</td>
<td>College students</td>
</tr>
<tr>
<td>molecules (the hydrogen atoms from water combines with the</td>
<td>Smith and Nakhleh (2011)</td>
<td>University students</td>
</tr>
<tr>
<td>cation of the salt and the oxygen atoms from water combines</td>
<td>Kelly and Jones (2007)</td>
<td>University students</td>
</tr>
<tr>
<td>with the anion of the salt)</td>
<td>Tien et al. (2007)</td>
<td>College and university students</td>
</tr>
<tr>
<td></td>
<td>Liu and Lesniak (2006)</td>
<td>Elementary to high school</td>
</tr>
<tr>
<td>Represent chemical reactants as multi particulate in chemical</td>
<td>Smith and Metz (1996)</td>
<td>University students</td>
</tr>
<tr>
<td>reactions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ionic solids dissolving as neutral formula units or ion-pairs—</td>
<td>Smith and Nakhleh (2011)</td>
<td>University students</td>
</tr>
<tr>
<td>for example, students believe that in water, NaCl ion pairs</td>
<td>Kelly et al. (2010)</td>
<td>University students</td>
</tr>
<tr>
<td>do not break apart</td>
<td>Jansoon et al. (2009)</td>
<td>First year university students</td>
</tr>
<tr>
<td></td>
<td>Kelly and Jones (2007, 2008)</td>
<td>University students</td>
</tr>
<tr>
<td></td>
<td>Tien et al. (2007)</td>
<td>College and university students</td>
</tr>
<tr>
<td></td>
<td>Liu and Lesniak (2006)</td>
<td>Elementary to high school</td>
</tr>
<tr>
<td></td>
<td>Butts and Smith (1987)</td>
<td>Year 12</td>
</tr>
<tr>
<td>Misconception/difficulty</td>
<td>References</td>
<td>Participants</td>
</tr>
<tr>
<td>----------------------------------------------------------------------------------------</td>
<td>----------------------------------</td>
<td>------------------------------</td>
</tr>
<tr>
<td>Intra-molecular covalent bonds are broken when a substance changes phase</td>
<td>Pabuccu and Geban (2012)</td>
<td>Year 9</td>
</tr>
<tr>
<td></td>
<td>Mayer (2011)</td>
<td>Year 10</td>
</tr>
<tr>
<td>Students did not write separately any ionic species in their representations of aqueous solution</td>
<td>Smith and Metz (1996)</td>
<td>University students</td>
</tr>
<tr>
<td></td>
<td>Boo (1998)</td>
<td>Year 12</td>
</tr>
<tr>
<td>Water evaporates and changes to air</td>
<td>Barke (2012)</td>
<td>Secondary students</td>
</tr>
<tr>
<td>Students failed or neglected to write the state of substance (s) for solid, (l) for liquid and (aq) for aqueous</td>
<td>Smith and Metz (1996)</td>
<td>University students</td>
</tr>
<tr>
<td>Students do not distinguish between ions, atoms and molecules (O²⁻, O and O²)</td>
<td>Barke (2012)</td>
<td>Years 10-12</td>
</tr>
<tr>
<td>Oxidation and reduction processes can occur independently</td>
<td>Yakmaci –Guzel (2013)</td>
<td>Pre service chemistry teachers</td>
</tr>
<tr>
<td>Matter consists of particles that are static. In the solid state, particles cannot vibrate in fixed position</td>
<td>Badrian et al. (2011)</td>
<td>Years 9-11</td>
</tr>
<tr>
<td></td>
<td>Boz (2006)</td>
<td>Years 6, 8, 11</td>
</tr>
<tr>
<td>Students thought that particles of gas do not fill a container</td>
<td>Badrian et al. (2011)</td>
<td>Years 9-11</td>
</tr>
<tr>
<td>Students did not understand that in the process of ice melting, the volume of the system (ice and water liquid) increases</td>
<td>Stojanovska et al. (2012)</td>
<td>High school and secondary school</td>
</tr>
<tr>
<td>Students do not understand the meaning of “aqueous” represented as “(aq)” and do not include water molecules in a reaction</td>
<td>Kelly et al. (2010)</td>
<td>University students</td>
</tr>
<tr>
<td></td>
<td>Smith and Metz (1996)</td>
<td>University students</td>
</tr>
<tr>
<td>Students have difficulty distinguishing between H₃O⁺ and OH⁻</td>
<td>Artdej et al. (2010)</td>
<td>Year 11</td>
</tr>
<tr>
<td>In dissolving sodium chloride in water (water makes the particles of salt smaller)</td>
<td>Taber and Garcia-Franco (2010)</td>
<td>Ages 11-16</td>
</tr>
<tr>
<td>Misconception/difficulty</td>
<td>References</td>
<td>Participants</td>
</tr>
<tr>
<td>----------------------------------------------------------------------------------------</td>
<td>-------------------------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>Students have difficulties understanding the differences between metallic bonding and ionic bonding. For example, metallic bonding looks like ionic bonding and the bonding in metal is a type of ionic bonding.</td>
<td>Kuathan et al. (2011)</td>
<td>Secondary students</td>
</tr>
<tr>
<td></td>
<td>Acar and Tarhan (2008)</td>
<td>15 years old</td>
</tr>
<tr>
<td>Students did not separate ionic species when showing the precipitation reaction</td>
<td>Smith and Mitz (1996)</td>
<td>University students</td>
</tr>
</tbody>
</table>

### 2.3 Information Processing Model

Given the difficulties of teaching and learning chemistry, and the misconceptions existing among students, consideration of changes in the instructional model is appropriate. Surprisingly, while misconceptions seem fairly well documented, 9 out of 10 chemistry instructors are unaware of the misconceptions, or do not explicitly tailor teaching to address them (Gabel, 1999). The question is how best to go about addressing chemistry teaching to improve student understanding. The information processing model helps set a framework for analysis about how to improve chemistry instruction and learning.

The information processing model sets the foundation for how students attend to, process, store, and retrieve audiovisual information. The information processing model forms the basis for the VisChem learning design described in Section 2.4. The information processing model is an educational theory used to explain how learning occurs, and has been recently reviewed (St Clair-Thompson, Overton & Botton, 2010). As described by Johnstone (1997), the information processing model consists of three basic stages: a perception filter, a working memory space, and the long-term memory (see Figure 2.3).
Applying the three-stage model (perception/working-memory/long-term memory), educational researchers have developed effective learning strategies by critically reviewing each element of the Johnstone model.

The “perception filter” recognises that individuals have varying abilities to "filter" incoming information, and some direction may need to be provided to students to assist them processing new information (St Clair-Thompson et al., 2010).

Short-term memory acts both as a place for temporary holding of information, and as a place for processing of information (Johnstone, 2006). Short-term memory is only able to accommodate limited “chunks” of information, so how much, and how fast, information is presented to students must be closely examined (St Clair-Thompson et al., 2010).

In contrast to short-term memory, long-term memory is the relatively permanent storage of information, referred to by some researchers as a holding place for cognitive schema (St Clair-Thompson et al., 2010). The schema act as mental representations used to organise and simplify the world, and with practice can even lead to automation of tasks (St Clair-Thompson et al., 2010). This long-term memory does not alter rapidly—indeed, if long-term memory were subject to rapid change, then it would lose its functionality as the more permanent store of information that reduces working memory load (Van Merrienboer & Sweller, 2005).
The elements of filtering, short-term memory and long-term memory are also interactive: long-term memory interacts with both short-term memory and with perceptions, and vice versa (Johnstone, Sleet & Vianna, 2006). Animations and simulations can assist students to build connections between the textual/auditory and pictorial/visual representations.

The process of forming connections works at two levels. At one level, connections are formed with reference to the particular topic or feature being taught: chunks of information are presented that ultimately will be formed into meaningful groups of information (St Clair-Thompson et al., 2010). The connections also work at a second, deeper level, as well: visualisations help link the otherwise abstract molecular level to the observable level that we see. This overall process of interlinking of information is central to effective student learning (Johnstone et al., 2006).

2.4 *VisChem* Learning Design

Many potential teaching approaches exist, and to improve chemistry teaching requires consideration of the presentation and methodology of the teaching (Johnstone, 1993). In this research, a seven step teaching method using a *VisChem* learning design and various visualisation objects were used. In this thesis this method is referred to as the molecular level visualisation approach. The evaluation of the molecular level visualisation approach differs from current instructional methods commonly found in Thailand (and elsewhere). In Thailand, teaching still occurs by what can be called a teacher-centred, and textbook based approach. As used in this research, that approach will be called the “traditional approach.”

The molecular level resource used in this research is from the *VisChem* collection of animations. The collection is a suite of animations that draws on, and applies, the information processing model as part of a seven-step learning design. Development of the *VisChem* collection was initiated in the early 1990s because there was a lack of resources depicting the molecular level (Tasker & Dalton, 2006). The *VisChem* project was developed with a primary goal of linking the three thinking levels (Tasker, Bucat, Chia & Sleet, 1996).
To be effective for teaching and learning chemistry by using *VisChem* animations, an audiovisual information-processing model has been integrated as depicted below:

**Figure 2.4.** An audiovisual information-processing model

According to Tasker and Dalton (2006, p. 148), the model depicted above is an “embellished” multimedia information processing model for learning from audiovisual information. The model draws on research by Mayer (1997) and Johnstone and El-Banna (1986), as well as directly or indirectly incorporating elements of generative theory (Wittrock, 1974), dual-coding theory (Paivio, 1990) and cognitive load theory (Sweller, 1994). The information processing model is described further below.

The information processing model treats students as active participants in the learning process. So, too, according to the generative theory, students are viewed as active participants in the learning process who work to construct meaningful understanding (Lee, Lim & Grabowski, 2008). Applying generative theory, Mayer (1997) assumes students select, organise, and integrate information, and can do so with reference to multimedia teaching materials. Similarly, the diagram in Figure 2.4 describes learning in terms of an audio visual information processing model in four stages including "perceiving" and "selecting" and "processing" and "encoding."

Tasker and Dalton (2006) noted that the audio-visual information-processing model above can guide those individuals interested in developing effective learning designs.
The learning design is composed of a series of “learning activities” (Tasker & Dalton, 2006, p. 151). The specific learning activities that would typically be a part of the design include observing, describing, discussing, viewing an animation (and possibly other visualisations), reflecting, relating and adapting (Tasker & Dalton, 2006). The VisChem learning design was developed with the understanding that these activities would play a role in teaching, and the design can be used for any chemistry topic that requires a scientifically acceptable mental model of particulate nature of matter. The VisChem learning design thus encourages a step-wise development of information gathering.

This careful, step-wise development of new information is consistent with cognitive load theory that assumes a limited working memory, and considers how new information is processed (Van Merrienboer & Sweller, 2005). For example, how new information is processed can be influenced by the difficulty of the topic itself (intrinsic cognitive load), as well as by how the material is presented (extraneous cognitive load) (Van Merrienboer & Sweller, 2005). While intrinsic load may not be capable of being reduced, the step-wise set of activities in the VisChem learning design is one way to reduce extraneous cognitive load. Pointing students to key features of animations is another way to reduce extraneous cognitive load.

Importantly, the VisChem learning design incorporates visuals, thereby implicating dual-code theory and potential benefits associated with combining visual and textual/pictorial elements. According to dual code theory (DCT), the use of images may be useful to the learning process (Paivio, 2006). Dual code theory posits two separate information processing systems: the verbally based and the non-verbally based (e.g., visual, auditory and haptic) (Paivio, 2006). Animations can help portray (i.e., the visual) the invisible molecular world, and do so with associated verbal instruction (Tasker & Dalton, 2006). In other words, the invisible molecular world can be made more concrete. Concreteness and imagery can have beneficial effects on memory (Paivio, 2006). Behavioural and psychological studies show that pictures and sounds are processed by different brain areas, and are thus functionally independent (Paivio, 2006). Similarly, text and pictures are processed differently (Mayer, 1997). The processing of these sounds, text or images is an event of
organising and building connections, and takes place in the short-term memory (Mayer, 1997). Combining the different elements—verbally based and non-verbally based (visual/auditory/haptic)—and forming the associated mental model has been described as an additive or bootstrapping process (Paivio, 2006). The verbal and nonverbal codes therefore act together and cognition comes from the activity between the two codes.

The following Table 2.2 summarises the steps of the VisChem learning design process:

Table 2.2

The learning process of teaching and learning chemistry based on the VisChem Learning Design (Tasker & Dalton, 2006).

<table>
<thead>
<tr>
<th>Learning Process</th>
<th>Level</th>
<th>Students</th>
<th>Teacher</th>
<th>Learning Theories and Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.Observing</td>
<td>Observable</td>
<td>Observe the chemical phenomenon from video or do experiments in the classroom</td>
<td>Stimulate students by using questions</td>
<td>Student centred; Teacher facilitated</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.Describing and</td>
<td></td>
<td>Describe in words and drawings a representation of what is occurring at the</td>
<td>The teachers will ask and explain about the need for drawing conventions, e.g., to indicate relative size, movement, number, and crowding of molecules</td>
<td>Prior-knowledge about mental model from students; Student centred; Teacher facilitated</td>
</tr>
<tr>
<td>explaining</td>
<td></td>
<td>molecule level to account for the observations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.Discussing</td>
<td></td>
<td>Discuss with classmates</td>
<td>Advise students to focus on the key features of the representation that explains the observations</td>
<td>Exchange ideas about prior knowledge; Student centred; Teacher facilitated</td>
</tr>
<tr>
<td>Learning Process</td>
<td>Level</td>
<td>Students</td>
<td>Teacher</td>
<td>Learning Theories and Strategies</td>
</tr>
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<td>--------------------------------------------------------------------------</td>
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<td>--------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>4. Viewing</td>
<td>Molecular</td>
<td>Students see the animations and other visual representations that show the phenomenon at the molecular level; Repeating the important information.</td>
<td>The teachers use animations and other visual representations to explain to students. Information processing model (the process of using a <em>VisChem</em> animation); Cognitive load theory (visual from animation and narration from teacher); Dual coding; Long term memory (repeat and explain in each key feature)</td>
<td></td>
</tr>
<tr>
<td>5. Reflecting</td>
<td></td>
<td>Teacher and students discuss the representation before and after viewing the animations and other visual representations</td>
<td>Teacher and students discuss the representation before and after viewing the animations and other visual representations</td>
<td>Constructivism, mental model change before and after viewing visual representations</td>
</tr>
<tr>
<td>6. Relating</td>
<td>Symbolic</td>
<td>Learn the symbolic level from writing the formula, equation and mathematics, and students link among the three levels</td>
<td>Teacher explains the symbolic level to students, and how to link the topic in three levels</td>
<td>Linking the three levels</td>
</tr>
<tr>
<td>7. Adapting</td>
<td></td>
<td>Students will be asked to use this mental model to explain another phenomenon</td>
<td>Teacher uses questions to help students to see similarities and differences</td>
<td>Apply the concept to a new situation, deep understanding</td>
</tr>
</tbody>
</table>
Tasker & Dalton (2008, p. 123) noted that the key criteria for the success of the VisChem learning design to promote visualisation as a learning strategy are the:

1. Constructivist approach;
2. Opportunity to discuss ideas and difficulties with peers;
3. Practice and application of the visualisation skills developed, with the explicit expectation that these skills are valued, and would be assessed for grading purposes

2.4.1 The VisChem Animations

To implement the molecular level visualisation approach in Thailand in this research project, a series of VisChem animations were used. These dynamic molecular-level resources are from the VisChem (Visualising Chemistry) Project. The VisChem Project developed a suite of molecular animations depicting the structures of substances and selected chemical and physical changes to help explicitly link the three levels (Tasker et al., 1996). These VisChem animations were integrated into videos to help students understand the relationship between the three levels of chemistry thinking. VisChem animations are unique because they portray the vibrational movement in solid substances (Tasker & Dalton, 2008).

The 3D visualisations provide an engaging and enjoyable way to learn, and are anticipated to motivate students. The VisChem animations are available in digital format from http://www.vischem.com.au. Some examples of the VisChem animations are presented below:
Figure 2.5. A frame from the VisChem animation showing reduction of silver ions to silver atoms, with the release of copper (II) ions (Tasker, 1998, p.3)

Figure 2.6. A frame from the VisChem animation which attempts to visualise gaseous water molecules 'pushing back' the walls of a bubble in boiling water (Tasker, 1998, p.4)

Figure 2.7. A frame from the VisChem animation showing the hydration of a sodium ion on the surface of sodium chloride despite strong attractive forces from the rest of the lattice (Tasker, 1998, p.5)
Use of VisChem animations has already been demonstrated to help students better understand the nature of substances and reactions at the molecular level, and to assist students to construct useful mental models. For example, Dalton (2003) collected data from 48 first-year university students using a pre-test/post-test, interview and transfer test protocol to examine the changes in mental models after learning with animations. The results demonstrated that students developed more "vivid mental imagery" of chemical substances and processes at the molecular level after exposure to VisChem animations, and they had "greater confidence in their images" (Dalton, 2003, p. 55). Some students were able to transfer their ideas from VisChem animations to new situations (but not necessarily to new topics). The same research indicated that showing animations to students, and teaching them to practise drawing representations of the molecular level, lead to better student understanding.

While the VisChem animations were used for Dalton’s research, the VisChem learning design or the molecular level visualisation approach has never been evaluated in a comparison approach juxtaposing results from the traditional approach and the molecular level visualisation approach.

Although use of VisChem animations has been investigated and used in Australia and other countries, more research is required to explore their potential in different educational contexts and levels. The focus of this research is on the use of VisChem animations in Thailand as part of a molecular level visualisation teaching approach.

2.5 Visual Representations

Visualisations are one element of the seven step visualisation approach, and animations are but one type of visualisation. Other kinds of visualisations exist such as pictures, diagrams, and ball and stick models. In this research, multiple visualisation types were used. Thus, for example, animations are complemented with textbook diagrams, ball and stick models, or pictures, or other visualisations already common in chemistry classrooms.
The research below discusses the usefulness of animations in general, and briefly touches on research relating to other visualisation methods, and the need to supplement these various methods with adequate guidance.

### 2.5.1 Visualisations in General

Although the VisChem learning design is a multi-step, and complementary, learning process, visualisations are an important part of the design. Visualisation methods are broadly recognised as being an effective teaching tool (Vavra, Janjic-Watrich, Loreke, Phillips, Norris & Macnab, 2011). Visualisation as a means of instruction—including computer based animations—has, in the minds of some, been underutilised (Mayer, 1997). Mayer (1997) hypothesised that learners are best able to build connections when presented with verbal and visual representations held in short term memory at the same time. The visual representations can encompass a broad range of objects, such as computer animations, diagrams, pictures, and ball and stick models (Vavra et al., 2011).

Many researchers have been trying to help students understand the molecular level by producing visual models (Bilek & Machkova, 2012; Dori & Barak, 2000; Supasorn & Vibuljan, 2009). Because technology is developing so rapidly, the pace of technological change and technological capability is moving faster than the corresponding scientific understanding about how people learn from pictures and words (Mayer, 1997). Nevertheless, the research that has been done shows considerable promise for using visualisation methods in the classroom (Clark & Chamberlain, 2014; Lee, Plass, & Homer, 2006; Mayer, 1997; Russell & Kozma, 1994; Tasker & Dalton, 2006).

### 2.5.2 Computer Animations

Computer animations are used increasingly in classrooms to help students better understand the dynamic molecular level. Many different animations and simulations have been developed. Examples include, eChem (Wu, Krajcik & Soloway, 2001), Chemdiscovery (Agapova, Jones, Ushakov, Ratcliffe & Maria, 2002), Chemation (Chang, Scott, Quintana & Krajcik, 2004), ChemSense (Kozma &

Some research shows that the teachers want to use computer animation to teach students in the classroom. For example, Boz and Boz (2008) collected data from twenty-two prospective chemistry teachers. Semi-structured interviews and a lesson plan were used to investigate prospective chemistry teachers’ knowledge about instructional strategies, and teachers’ pedagogical content knowledge (instructional strategy for a particular topic). The elements of Pedagogical Content Knowledge (PCK) were complex and varied by instructor, but computer animations, visual representations, and drawings were common instructional choices.

Although some kinds of computer animations have been produced, teachers often find errors in the images and animation sequence and they do not want to use them in the classroom (Burke & Greenbowe, 1996). The time it takes to use an animation can also be a drawback. These drawbacks may be the reason that many teachers still prefer to teach students with the traditional approach.

Animations as a part of an overall instructional design have been shown to be effective. For example Wu, Krajcik and Soloway (2001) investigated how students developed an understanding of chemical representations (symbolic level such as formulas or symbols) with the aid of visualising tools (in that case, eChem). The authors collected data from 71 11th Grade students in a public high school. The results from a video recording and interviews showed that many features in eChem helped students construct 3D models and translate chemical representations such as formulas, symbols, and so on. The authors noted, however, that to be successful, computerised models need to be effectively linked to other forms of representation (formulas, 2D models, and so on) through explanation, computer design, or otherwise. The authors also noted that the visualisation tool provided a positive motivational effect on students that also could have influenced the results. Notably, this research did not compare the learning outcomes between the group using the visualisation tool (eChem) and the group not using that tool.
Williamson and Abraham (1995) also showed that animations can be effective. They studied the effect of computer animation on the particulate mental models of college chemistry students. The particulate nature of matter evaluation test (PNMET) was used to determine the nature of the students’ visualisation and chemistry concepts. Animations were used in two treatment situations: 1) supplementing large-group lectures, and 2) as assigned individual activity in computer laboratories. The results from the large-group and individual laboratory activities were compared to results from a control group. The results showed that the two treatments groups obtained higher scores on PNMET than the control group. The authors also suggested that teaching students in a small group was more effective than a large group.

Marbach-Ad, Rotbain and Stavy (2008) also evaluated the use of animations with their students. The data was collected from three groups including a computer animation (61 students), illustration (71 students) and a control group (116 students). The results showed that the computer animation and illustration groups scored higher than the control group. Computer animation was recommended for teaching and learning in molecular genetics with dynamic processes because the answers to open-ended questions showed that the computer animation activity was significantly more effective than the illustration activity. However, students in the illustration group still improved their achievement more than the group given the traditional approach.

Although research suggests a positive role for the use of computer animations to help students understand the molecular level, some point out inconsistent results when using animations (Cook, 2006), or question the actual benefits (Geelan, 2012). Geelan (2012) argued that there were no significant differences in conceptual development between the students taught with and without visualisation. He studied 129 students in Year 11 with the topics of Le Chatelier’s principle, intermolecular forces and thermochemistry. He compared two groups taught with and without computer animations. A cross-over research design and pre-test and post-test were used. The result from a two-tailed independent-samples t-test revealed no significant difference between the groups ($t(256)=-.538, p=.59$). However, there was a significant indication that students enjoyed learning with visualisation even if the conceptual development was not different between the groups (Geelan, 2012).
The results described by Geelan (2012) may be due to the nature of the questions asked, or the manner in which the visualisations were applied, neither of which appear to be the focus of the Geelan research. Questions that ask for diagrams or explanation about molecular level processes may probe "deep understanding" more effectively than formula questions. For example, if we ask students to explain about vibration and movement of particles in the molecular level, then without visual models the students cannot provide an adequate explanation because they cannot imagine the phenomenon at the abstract level. Therefore, computer animations can portray and help students build an appropriate mental model at this level better than without computer animations (Marbach-Ad et al., 2008; Russell & Kozma, 2005).

Another potential drawback about animations is that they can result in misconceptions. Rosenthal and Sanger (2012) investigated student misconceptions and misinterpretations of two-computer animations of varying complexity depicting the same oxidation-reduction reaction of aqueous silver nitrate and solid copper metal. A group of fifty-five students were asked to explain their understanding after viewing two computer animations. The results showed that students had misconceptions and misinterpretations after viewing the complex animations. For example, a student said:

We saw that the silver from the nitrate (red/white shapes) is breaking apart, and the silver is connecting to the solid copper and you can see that the yellow part is slowly being taken from this, so it could be copper and nitrate…Copper started as solid and became aqueous when it connected to the nitrate (Rosenthal & Sanger, 2012, p. 476).

This and similar misinterpretations may be because of the lack of teacher introduction of the visual conventions used before and during the animation. To be effective for teaching and learning chemistry with computer animation, Tasker and Dalton (2008) suggested the models must be designed and presented with great care in order to encourage students to focus on the intended “key features.” Cook (2006, p. 1083) similarly describes the need to “cue” student attention to the relevant animation details. The animations must avoid generating or reinforcing
misconceptions. For example, the colours and shapes of animated molecules may be incorrectly assumed to reflect the actual reality of the presented item (Tasker, Dalton, Sleet, Bucat, Chia & Corringan, 2002).

In summary, computer animations have been analysed and shown to be a potentially effective chemistry teaching tool. Although computer models can help students to develop thinking in the molecular level, and to link the molecular level to phenomena at the observable level, the use of computer models still needs to be investigated to develop best practices for the classroom.

2.5.3 Other Visualisation Elements

Animations present a relatively new element in the Thai classroom, and form a focus point in this research. Animations are obviously only one of many, possible, visualisation objects (Vavra et al., 2011). Other visualisation objects are frequently used such as diagrams, pictures, and ball and stick models. These various visualisation objects have been found to assist in teaching, and can be useful depending on the particular purpose they are used for (Vavra et al., 2011). While static displays may fail as a means of understanding particulate behaviour, research generally supports the idea that visuals aids assist with overall concept understanding (Williamson & Abraham, 1995). Noh and Scharmann (1997) undertook to present 11th Grade Korean students with 31 pictorial elements for the topics of diffusion and dissolution, and particle and state. The results showed improvement for diffusion and dissolution (relatively dynamic), but not for particle and state (less dynamic). The study concluded that the pictorial elements could be effective for new or difficult concepts, in part simply because conceptual elements were emphasised more so than during traditional instruction.

A common theme of research relating to visualisations—whether we are talking about diagrams, or animations, or pictures, or some other visualisation—is that the “visualisations are not effective in isolation” (Vavra et al., 2011). “Instructional guidance plays an important role in learning from visual representations, particularly when instruction requires active construction of knowledge” (Cook, 2006, p. 1084) When combined with verbal or textual
information, and with explicit explanations or guidance, the various visualisation elements can act as an effective aid for understanding (Vavra et al., 2011).

The main aim of this research is to evaluate a molecular level visualisation approach. To do so, the VisChem animations were used as the main, or primary, visual representation. However, because of the general utility of other visualisation objects, these animations were combined with pictures and diagrams as the teacher drew them on a blackboard after using animations. Results and findings from this molecular level visualisation approach are described in detail in Chapter 5, and suggest a positive role for this molecular level visualisation approach.

2.6 Deep Understanding

2.6.1 What is Deep Understanding?

"Understanding" is a deceptively simple concept. Understanding as a general goal is acknowledged as a worthwhile and valued goal in education (Newton, 2001b). But what does the term mean?

Understanding is something more than "mere retention of the material," (Mayer, 1997) or the ability to conduct a laboratory experiment (Johnstone et al., 2006). It is the ability to use the information to apply to new problems (Mayer, 1997). Newton (2000) describes understanding as the ability to make connections between facts and ideas and to see relationships and patterns. Newton (2001a) noted that understanding is both a mental process and a mental product. The process is the ability to use what you know; the product is the understanding.

"Deep understanding" can be thought of as something existing on a continuum. Holt (1964) raised the question of what it means to “understand.” He set forth a series of questions intended to probe what we generally believe when we believe we understanding something:

I feel I understand something if and when I can do some, at least, of the following:
1) state it in my own words; 2) give examples of it; 3) recognise it in various guises and circumstances; 4) see connections between it and other facts or ideas; 5) make use of it in various ways; 6) foresee some of its consequences; 7) state its opposite or converse (Holt, 1964, p.36-37).

Holt (1964) juxtaposes the understanding here with what he called “apparent learning,” i.e., learning that might be for the purposes of achieving a good test score. A good test score may display knowledge of a fact—an understanding—but understanding exists at a deeper level where a person knows how facts and topics might relate to, compare with, and fit in with each other (Holt, 1964). Well represented and well connected concepts have been described as deep understanding (Zirbel, 2007). At least according to what Bereiter (2006) calls performance perspective, understanding is measured by the quality of performance (i.e, the ability to explain, evaluate, and apply). As described by Chandrasegaran, Treagust and Mocerino (2008), a deep understanding requires the ability to link various concepts or sub-concepts both hierarchically and laterally.

In this research, we are concerned with students’ ability not only to respond to traditional questions in chemistry at the symbolic level, but to examine students’ ability to explain and evaluate information and apply it across the three levels of thinking (molecular, symbolic, observable), i.e., a deeper understanding as displayed by well represented and well connected concepts. Understanding the various levels and how they work together was described in one paper as “integrated conceptual understanding” (Krajcik, 1991; Chandrasegaran et al., 2008).

"Deep understanding" is to know and understand something in a more meaningful way even if we cannot precisely define it. Bereiter (2006) says that deep understanding means understanding deep things about subjects worthy of our students’ attention. He said “we use the term with confidence, even though we cannot define it, and evaluating it is highly subjective” (Bereiter, 2006, p.11).

"Deep understanding"—although not called that in so many words—is ultimately a goal of the information processing model. Changes to long term
memory have been described as the "most important characteristic that influences learning and performance" (St Clair-Thompson, 2010). In this project we evaluated student comprehension of the concepts taught by interviewing the students and analysing the depth of their knowledge. Have the students "learned" the chemistry information in a way allowing them not only to answer test questions properly, but also to describe and apply the concepts accurately?

To achieve "deep understanding" requires being able to move between the invisible molecular world, the symbolic representations, and the world that we can see. Visualisation techniques can assist to make those connections.

2.6.2 Assessment of Deep Understanding in the Literature

The ambiguity inherent in the term “deep understanding” has, predictably, lead to a variety of uses of that term and whether, and how, it might be assessed. Some researchers appear to assume that “deep understanding” as a goal requires no further explanation or measurement. (Simon & Cutts, 2012; Strauss, 2001). An idea or change in teaching that should help students understand a concept better may be assumed—correctly or not—to lead to “deeper understanding.” At other times “deep understanding” appears to be equated with better grades or reductions in class failure rates (Waldrop, 2015). Clearly, though, better grades or class failure rates are only a rough measure of understanding and will not be used in this thesis.

Some researchers examined understanding as a function of a particular student’s self-conception, and contrasted student learning styles that were either “deep” or “surface.” (Burnett, Pillay, & Dart, 2003). This particular kind of research examined how students learned without examining particular class outcomes. In one study, assessment occurred via three testing instruments: What Is Learning Survey; the Learner Self-Concept Scale; a modified version of the Learning Process Questionnaire (Burnette, Pillay, & Dart, 2003). Students were categorized as having adopted either a deep, surface, or achieving approach to learning. This thesis does not examine or try to quantify the influence of a particular student’s self-conception on his or her learning approach, and therefore does not adopt this assessment model.
Finally, some researchers have adopted qualitative and quantitative approaches to measuring “deep understanding.” One interesting approach for examining “deep understanding” in chemistry was to categorize the questions asked by students (procedural, developmental, administrative) and then compare the types of questions asked over the course of a semester (Paideya & Soorajh, 2010). The questions might reveal transformations or development in student thinking. In another recent study, the stated goal was to apply a “deep approach” to a particular project where students developed a podcast. To measure learning outcomes, a quantitative approach was used involving a marking scheme to analyze the podcasts developed by the students. Certain criteria were required of each podcast, and then the actual content of the podcast was graded after which a t-test and analysis of variance was conducted (Pegrum, Bartle, & Longnecker, 2014). In general, assessments using open-ended questions and probing questions is another common way to measure “deep understanding,” as are drawing maps, informal quizzes, and general problem solving (Paideya & Soorajh, 2010).

While “deep understanding” (or “understanding” in general) is a complex topic, that does not mean the concept is not worthy of analysis, or that it should be avoided. As described in Chapter 3, by using carefully crafted open-ended questions and interviews, it is possible to measure student understanding in particular context and for a particular purpose.

2.7 Conclusion

This literature review reveals a general consensus that chemistry is difficult to teach, and that students often display a variety of common misconceptions. What, exactly, to do with that information remains a topic of lively discussion. At least one commentator bemoaned the fact that student misconceptions in chemistry are often identified and then followed by “bland statements about preventative or curative actions” (Bucat, 2004, p. 215).

This research offers actual in-class observations and data analysis followed by a specific recommended seven-step teaching approach and a detailed syllabus (see Section 6.5) on the topic of dissolving sodium chloride in water. The teaching
approach draws on studies that analyze student learning—the so-called “information processing model.” Multiple kinds of visual representations are incorporated; this is consistent with the research which has generally recognized a role not only for animations, but for static forms of representation as well.

Recent articles point to an international shift in teaching styles away from “traditional” methods and towards forms of “active learning” (Waldrop, 2015). Classroom chemistry teaching goals are said to be shifting to a curriculum aimed at promotion of deep conceptual understanding (Herrington & Yezierski, 2014). These recent shifts require systemic changes in how teaching is viewed, and in the knowledge base of instructors (Waldrop, 2015; Herrington & Yezierski, 2014). This research adds to the field by promotion of context specific applications to the Thai classrooms applying a rich data set drawn from multiple school settings, and multiple instructors.

This thesis adds to the incremental and step-wise development of chemistry teaching knowledge as applied to the Thai context. Nevertheless, promotion of “understanding” involves a “dizzying dance” where assessments, curriculum, student, teacher, and society and other factors all intersect (Heick, 2012). As noted in Chapter One, although Thailand has broadly subscribed to shifting from teacher-centred to student-centred learning (Section 1.3.1), that has not happened. Additional research particular to the reasons for the slow rate of change as applied to the sciences would be worthwhile. The way or ways effectively to transfer knowledge to new situations—Step 7—is a promising area for further research (Section 6.4). Meanwhile, particular recommendations for further research arising out this research are also mentioned below in Section 6.6.
CHAPTER 3

METHODOLOGY

This research applied a mixed method approach to both phases of the research. In Phase I of the study, VisChem animations and their efficacy in the classroom were explored, and in Phase II, the molecular level visualisation approach to promote secondary school students’ deep understanding in chemistry was implemented and evaluated. The basis for applying a mixed method approach, and the tests used and developed for this approach are presented in this chapter. Ethics and trustworthiness will also be addressed.

3.1 Mixed Methods

Mixed method research has been described as being in its adolescence (Leech & Onwuegbuzie, 2009). Some researchers contend that the approach has been around for a long time whether or not it was ever called a mixed method approach (Creswell, 2012). Recently there has been more mixed method research performed, and some predict it will become a leading research paradigm (Leech & Onwuegbuzie, 2009).

This research does not attempt to canvass the considerable mixed method literature that now exists but, instead, will employ this basic working assumption: mixed method can be effectively used as a kind of multiple ways of seeing approach (Creswell & Plano Clark, 2011). Neither the quantitative nor the qualitative approaches may, taken alone, provide a full or adequate data base. Quantitative approaches may not fully or adequately reflect or address the Thai classroom conduct (something not easily susceptible to a numerical test), and on the other hand qualitative approaches alone may lack the scientific rigor necessary to evaluate student performance after customary in-class written testing. The benefit of mixed methods use derives, in part, because the methods can complement each other (Pole, 2007).
While this research is not focused on usefulness of the mixed method approach per se, some explanation of the method is still appropriate. At its most basic level, a mixed method research is a research design that mixes, collects and analyses both quantitative and qualitative methods together in a single study, or multiple studies, to answer the research questions and to understand the research problem (Creswell & Plano Clark, 2011). Greene, Caracelli and Graham (1989) viewed the mixed methods approach as combining two distinct methods. Other researchers point out the mixed method approach might also be treated as a methodology which takes as its premise that the combined approach is better than either approach alone (Creswell & Plano Clark, 2007).

While individual definitions of mixed method may vary by researcher, general consensus would seem to exist that the approach applies quantitative and qualitative elements in some fashion. As both quantitative and qualitative methods will be applied in this research, at least a brief discussion about those two methods will be provided. In general, quantitative research tends to examine larger numbers of people according to statistical means, whereas qualitative research involves smaller numbers of people where a research topic may be examined through questions to probe deeper understanding. Creswell (2012) framed certain, particular elements of quantitative and qualitative research. Each type of research can be used for varying purposes, such as analysing broad trends through statistical means, on the one hand (quantitative), or collecting a smaller group of data based on views of particular individuals (qualitative). Elements of qualitative and quantitative methods are used in this research. For quantitative measures, this research collected numeric data from student testing, compared groups of students, and applied research using fixed evaluation criteria. Qualitative measures included elements like class observation, and student interviews.

Both qualitative and quantitative methods have strengths and weaknesses. When best to use the methods (or mixed methods methodology) requires consideration of the research topic and goals (Creswell & Plano Clark, 2011). The purpose of this research was to first explore and investigate teaching chemistry by using the animations, and next to evaluate the molecular level visualisation approach for teaching and learning chemistry to promote secondary school students’ deep
understanding. Using multiple tools of analysis—questionnaires, video recordings and interviews—involving both quantitative and qualitative elements, provides the advantage or potential of corroboration (convergent findings), elaboration (richness of detail), initiation (turning ideas around), and reconciliation (resolve contradictory findings) (Kumar, 2007).

This research examines how chemistry instruction occurs in a Thai context, and in a Thai classroom, and the benefits of visualisation as applied in that context. Quantitative methods offer the advantage of a broad, statistical set of raw test result data from which generalisations may be made. Qualitative measures, by contrast, may yield important supplemental information not necessary gleaned solely from the quantitative data. For example, viewing the classroom teaching methods, viewing the students, or inquiring more precisely with particular students about their understanding may provide insights not available through quantitative means. The aims of this research therefore seem best met through a mixed method approach.

Although mixed method research has been commonly applied, it has disadvantages. The researcher using mixed method techniques must understand the data collection technique and data analysis formats, while applying both quantitative and qualitative methods, and the overall process can be complicated and time consuming (Creswell, 2012). Although this study was indeed time consuming and done in phases, and in multiple schools, and applying multiple test formats, in the researcher’s opinion this approach enabled a more complete picture of the current state of chemistry teaching in Thailand which should result in a stronger study with better inferences (Pole, 2007).

While multiple labels could, potentially, be used to describe this research (Creswell, 2011), at least one way to describe the method is “sequential.” This research was sequential in two respects: first, and most obviously, the research was conducted in two phases. Second, qualitative analysis generally followed preliminary quantitative data analysis. Therefore, generally, observation of the videotapes, or conduct of interviews, occurred after some preliminary quantitative data was obtained. At least in some respects, the research was not strictly sequential. For example, where calculation and drawing tests were administered, quantitative
and qualitative analysis occurred more or less at the same time. Yet, overall, to the extent a research design label is used to describe the mixed method style, this researcher prefers to think of the study as being sequential.

3.2 Ethical Considerations

The main ethical considerations related to student and teacher participants are obtaining informed consent, and respecting privacy and confidentiality. Ethics should be a primary consideration in development of any research, and not simply an afterthought (Hesse-Bieber & Leavy, 2006). The Human Research Ethics Committee for the University of Western Sydney (EC00314) reviewed and approved this research (see Appendix A).

Informed consent of participants is considered their right (Creswell, 2012). Respect for the schools and location of the research is also important as the researcher is, in essence, a guest who should cause as little disruption as possible (Creswell, 2012). Preliminary consent was obtained by outreach to school administrators in Thailand. A permission letter was sent to the principal in each school. Teachers were then contacted, and the goals and purposes of the research were explained to them by the researcher, and usually on more than one occasion. After that, the research was explained to students who participated in this project. The participants were Grade 11 students, and consent forms were obtained from both students and parents (see Appendix B). To protect the identity of individual students or teachers, and to minimise the chance for embarrassment or loss of privacy, only pseudonyms have been used in reporting test results.

Fairness to all participants was considered. Specifically, students who may have been in a control group may have felt it was unfair that other students got to observe animations as a part of the instruction. Students in control groups therefore were also given the opportunity to be taught by animations or the molecular level visualisation approach either after school or during free periods. Many students availed themselves of this opportunity. In this way, all students had roughly the same opportunity to experience the animations or instruction using the molecular level visualisation approach.
3.3 Trustworthiness

Research quality is determined in part by the trustworthiness of the results. Here, the trustworthiness of the results is enhanced through triangulation. Triangulation means gathering and analysing data from more than one source to gain a fuller perspective on the situation being investigated, to cross-check, and to assess the authenticity of individual accounts (Bell, 1993).

Triangulation aids with trustworthiness because, as Patton (2002) explains, different methods will reveal different aspects of the research. In essence, multiple methods can reveal different aspects of the problem. Denzin (1978) identifies triangulation of four basic types: data triangulation, investigator triangulation, theory triangulation and methodology triangulation. The last triangulation type listed—methodology triangulation—is widely used in social sciences. It applies at the level of research design of data collection (Burns & Grove, 1993).

Methodology triangulation comes in two forms: within-method and between-method (Modell, 2005). Either multiple methods can be applied to the research, or within a single type or kind of method, multiple strategies are used. This research used diverse methods such as interviews, drawings, and observation of classroom instruction. This approach is, in essence, a between-method triangulation (Denzin, 1978; Johnson, Onwuegbuzie & Turner, 2007). The between-methods approach is generally favoured because the differing methods reduce bias and lead to a convergence of the truth of what is being investigated (Johnson, Onwuegbuzie & Turner, 2007). Alternately stated, the differing methods provide a richer database from which to draw (Merriam, 1998).

For this research, data collected from Phase I (2012) and Phase II (2014) are reported in detail (see Chapters 4 and 5). The observations occurred over time, and with a variety of participants in different schools and in different settings. The variety of observations and settings allows one to generalise from the results (Merriam, 1998). This research also used mixed qualitative measures with various quantitative method measures, which—as noted above—acts as a kind of cross-check on the results obtained. The reliability of the questionnaire was checked, and the
Cronbach’s alpha was used to assess a coefficient of the reliability or consistency of the questionnaire (Cronbach, 1951). Moreover, all data collection techniques were subject to pilot studies prior to data collection for this research being undertaken.

Finally, a brief note will be provided about translation. This research was conducted by field studies in Thai classrooms with Thai teachers and students. The tests were developed in English, and then translated to Thai. The interviews were in Thai. Translation to and from English was necessary. The translations were performed by the researcher in consultation with a Thai professor who is well versed in both languages and has published in English and Thai science journals.

3.4 Research Design and Timeline

To evaluate animations and the molecular level visualisation approach, a two phase research design was implemented. The details of the research design are depicted in Figure 3.1.

![Research Design Diagram](image)

**Figure 3.1.** The research design and timeline

Phase I of the research explored the use of the *VisChem* animations, and whether incorporating the *VisChem* animations could have a positive influence on
Thai secondary school chemistry instruction. VisChem animations have never been used in Thai classrooms. Research specific to VisChem animations—or animations in general in Thailand—is generally lacking. Therefore, before conducting more detailed research about animations in Thai classroom, a preliminary assessment was conducted. Phase I was subdivided into three distinct studies. Study 1 was a pilot study using the VisChem animations. Study 2 compared an animation group to a group where no animations were used. Study 3 applied the VisChem animations in three different schools located in different geographic areas.

Phase I confirmed the general viability of using animations in the Thai classroom. Phase II implemented a molecular level visualisation approach to promote deep understanding in chemistry. This molecular level visualisation approach used VisChem animations, pictures and diagrams, and a seven step learning design. This phase of the research evaluated the molecular level visualisation approach for teaching and learning chemistry to promote secondary school students’ deep understanding. Three classes were used, and different teaching methods were applied in each class. The same teacher was used for all three classes. Class A used a traditional approach. Class B used the traditional approach, again, but with animations. Class C used the molecular level visualisation approach.

The data collection techniques and data analysis that were used for this research are described below.

3.5 **Data Collection Techniques**

The data in this research were obtained through various data collection techniques. The details of data collection techniques are described below.

3.5.1 **Transfer Tests**

Multiple choice test and calculation tests were used to answer whether students developed a deep understanding after learning with a traditional approach, a traditional approach using animations, or the molecular level visualisation approach.
Transfer tests were used to assess student deep understanding in chemistry for Phase II. The details of the transfer tests are described in the sections below.

### 3.5.1.1 Multiple Choice Test

During Phase II, students were presented with 10 multiple choice questions with five possible responses for each question (see Appendix C). Students were asked to choose the best possible answer. The questions used were specially developed to probe student understanding, and whether students could transfer knowledge gained in the classroom to new, but related, chemistry concepts in Thai secondary school in Grade 11.

To test deep understanding, the questions were different from the topics that were taught in classrooms. The multiple choice test was adapted from a questionnaire developed and produced by Mulford and Robinson (2002). The test was developed and refined to fit the secondary school student knowledge base by a professor who has over 30 years’ experience in chemistry teaching in university and a teacher who has more than 17 years’ experience teaching chemistry in secondary school. The reliability of the multiple choice test was assessed using Cronbach’s alpha. The Cronbach’s alpha value was 0.73.

Using a multiple choice test to evaluate students’ conception is common (Nakhleh, 1993; Sanger & Greenbowe, 1997; Dalton, 2003). The disadvantages of multiple choice tests are that they are normally used with lower-order skills, and they can be easy to guess. Nevertheless, multiple choice tests allow data to be collected from a large number of students, and multiple choice tests can be quickly coded and cumulated to give frequencies of response (Cohen, Manion & Morrison, 2000).

### 3.5.1.2 Calculation Test

The calculation test was also applied to assess the depth of students’ understanding. The test was checked and refined by the same educators who helped to develop the multiple choice test. The reliability of the calculation test was assessed using Cronbach’s alpha. The Cronbach’s alpha value was 0.80.
Students were asked to calculate the concentration of the ions in the solution. Students then had to draw the arrangement of the particles at the molecular level. This test was important because students are widely known to be able to resolve chemistry test questions without understanding the underlying molecular level events (Jansoon et al., 2009). The calculation with drawing test could assess whether the students could resolve the calculation problem, but also importantly, whether the students understood at the molecular level. An example of this test can be found at Appendix D.

3.5.2 Drawing Test

The drawing test was used for both Phase I and II. Students were asked to draw and explain the arrangement of the particles at the molecular level. A total of four drawing tests were used in this research, three tests for Phase I, and one test for Phase II (see Appendix E). The drawing tests were checked and refined by the same educators who helped develop the multiple choice and calculation tests. The reliability of the drawing test was assessed using Cronbach’s alpha. The Cronbach’s alpha value was 0.83.

The data from the drawing test was used to assess whether students’ mental model changed. A draw and explain test is a kind of opened-end questionnaire that is useful to test students’ understanding at the molecular level. Pre-tests and post-tests were used to collect data. Many research studies have used the drawing test to assess student understanding at the molecular level (Dalton, 2003; Kelly et al., 2010). Student generated drawings can reveal aspects of students’ understanding not otherwise obvious through calculations or multiple choice type questions (White & Gunstone, 1992).

Potential limitations with these drawing tests must be acknowledged. Draw and explain questions may be easy to ask, but difficult to answer, and more difficult yet to analyse. Moreover, it is difficult for the researcher to make comparisons between respondents, and it takes much longer to answer and analyse than other available test forms (Cohen et al., 2000). Notwithstanding these legitimate concerns, it is this researcher’s conclusion that draw and explain tests had more advantages.
than disadvantages, in large part because the drawings and explanations could quickly reveal depth of understanding of molecular level events.

3.5.3 Observation

In-class observation was done primarily through the use of video recordings for both Phase I and Phase II. The data from observation of the videorecording was used to answer the research question of how teachers teach.

The purpose of observation is to be able to describe the setting, to articulate the activities observed, and ultimately to be able to uncover meaning from the perspective of the people being observed (Patton, 2002). Video recordings were used instead of live observation to try and keep the classroom atmosphere and activities as authentic as possible, and to limit the chance for a third party presence disrupting or unduly influencing the teacher, the students, or the overall teaching approach. Using visual materials such as video recording is becoming increasingly popular in qualitative method research, particularly because of the rapidly evolving technologies that make this data gathering method accurate and reliable (Creswell, 2012).

3.5.4 Interviews

Semi-structured interviews were used to collect data after students completed their post-test during Phase II after the visualisation approach was complete (see Section 5.3.2.2). Burns (1998) believed that a semi-structured interview where the interviewer maintains some control over the interview offers more flexibility than close-ended type of interviews. He commented on the advantages of the semi-structured interview: 1) Rapport between researcher and participants increases, particularly when the participants are interviewed more than once; 2) The focus is on a given participant’s perspective and understanding; 3) The participants can use their own language to answer questions and describe their understanding; 4) The participants are on equal status to the researcher. The researcher believed that direct interaction with the students in the classes in a semi-structured format, and with
reference to particular drawings, could enable a window into student thought processes regarding their learning experience.

The semi-structured interview protocol was checked and refined by the educators as above. The semi-structured interview data were used in conjunction with a drawing test which revealed whether students did or did not retain misconceptions after using a molecular level visualisation approach. The drawing test results were analysed prior to interviews to get a preliminary look at pre-test and post-test results. Semi-structured interviews were then conducted to ask students in Phase II taught with the visualisation approach why misconceptions lingered, and how their mental models had changed. The interview protocol is available in Appendix F.

Students were selected for voluntary interview based on their responses. For the fourteen key features of the drawing test (described below in more detail), the volunteer students either had incorrect answers pre-test and post-test, or improved from incorrect to correct responses. Twenty-eight students participated, one for each kind of response (i.e., either incorrect answers pre-test and post-test, or improving from incorrect to correct, applied to each of the fourteen questions). The students’ whose mental model changed were interviewed to determine, if possible, the “why” for the change. This form of semi-structured interview has been accepted as a way to examine and monitor student understanding (Kelly & Jones, 2007). Factors influencing mental model change were then isolated and discussed in Section 5.4.3 as a way to probe the effect that the animation may have had on mental model change as compared to other potential causes. This research probed deep understanding rather than particular understandings, therefore the concern about comparability between interview results was not as high as it might be in other contexts. In other words, no particular understanding was at issue. The opportunity to question students first-hand is arguably one of the most straightforward means available to test deep understanding, and on balance the benefits of using semi-structured interviews outweighed the risks.
3.6 Data Analysis

How the data were analysed is discussed below.

3.6.1 Analysis for the Multiple Choice Test

Statistical Package for the Social Science (SPSS) was used to analyse the data obtained from the multiple choice tests (Creswell, 2012).

Comparing the results in the same group, such as comparing pre-test and post-test, was done by a paired sample t-test. If comparison among three groups occurred, a one-way analysis of variance (ANOVA) was used to determine whether there were any significant differences between the mean test results of three or more independent groups (Gerber & Finn, 2005). Therefore, ANOVA was used to compare the results of deep understanding among the class using a traditional teaching approach, the class using a traditional approach and animations, and the molecular level visualisation approach class.

3.6.2 Analysis for the Calculation Test

Students would obtain a “1” score for a correct answer coupled with an appropriate resolving method, and a “0” score for incorrect answers. Whether students obtained a correct or incorrect answer for the concentration in each ion was analysed, and the process the student used to resolve the problem was also analysed and coded. This data allowed inquiry into whether students understood at a deep level after learning with the three approaches in Phase II, especially with the visualisation approach.

The drawing component added supplemental information with reference to certain key features and associated scoring rubric. The results from both calculation and drawing parts were analysed with a conceptual evaluation marking scheme which was adapted from Haidar (1997), and Westbrook and Marek (1991). (see Table 3.1).
Table 3.1

Conceptual evaluation scheme

<table>
<thead>
<tr>
<th>Conceptual Evaluation Scheme</th>
<th>Student Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sound Understanding (SU)</td>
<td>The students submitted a correct answer for the calculation test.</td>
</tr>
<tr>
<td></td>
<td>The students also drew the arrangement of the particles correctly 80-100% with</td>
</tr>
<tr>
<td></td>
<td>reference to the relevant key features.</td>
</tr>
<tr>
<td>Partial Understanding (PU)</td>
<td>The students submitted a correct answer for the calculation test.</td>
</tr>
<tr>
<td></td>
<td>The students also drew the arrangement of the particles correctly 50-79% with</td>
</tr>
<tr>
<td></td>
<td>reference to the relevant key features.</td>
</tr>
<tr>
<td>Partial Understanding with</td>
<td>The students submitted a correct answer for the calculation test.</td>
</tr>
<tr>
<td>Misconception (PUM)</td>
<td>The students also drew the arrangement of the particles correctly less than 50%</td>
</tr>
<tr>
<td></td>
<td>with reference to the relevant key features. Alternatively, the students</td>
</tr>
<tr>
<td></td>
<td>submitted an incorrect answer for the calculation test, and drew the arrangement</td>
</tr>
<tr>
<td></td>
<td>of the particles correctly more than 50% with reference to the relevant key</td>
</tr>
<tr>
<td></td>
<td>features.</td>
</tr>
<tr>
<td>Specific Misconceptions (SM)</td>
<td>The students submitted an incorrect answer for the calculation test.</td>
</tr>
<tr>
<td></td>
<td>The students also drew the arrangement of the particles correctly less than 50%</td>
</tr>
<tr>
<td></td>
<td>with reference to the relevant key features.</td>
</tr>
</tbody>
</table>

3.6.3 Analysis for the Drawing Test

To analyse the data from the drawing test, a marking scheme was adapted from Dalton (2003). The drawing test for Phase II was developed for basic chemistry instruction in five topics, and key ideas/features were developed in relationship to each topic (see Figure 3.2). In total, 14 key features were identified.

The drawings pre-test and post-test in each key feature, and for each student, were marked according to this general scheme. As to every key feature, students were marked with (/) if they gave a correct answer, and they were marked with (X) if they gave an incorrect answer. Each key feature was analysed with reference to four mental model changes as follows:

// = Correct answer both pre-test and post-test
/X = Correct answer pre-test and incorrect answer post-test
XX = Incorrect answer both pre-test and post-test
X/ = Incorrect answer pre-test and correct answer post-test
3.6.4 Analysis for the Observation and Interviewing

Video recording of classroom instruction, and interviewing students, were used to collect data. Analysing this information was a multiple step process adapted from Creswell (2009). The process of data analysis can be seen in the following Figure 3.3:

![Diagram of Data Analysis Process]

Figure 3.3. The process of data analysis in qualitative research
Data collected from video recording (activity in the class, and interviews) is called raw data. The raw data were transcribed, and then all data were read and checked by the researcher to ensure that the transcription is the same as video recording. Reading through the data helps the researcher obtain a general sense of the information, and to reflect on the overall meaning of the information. During this process, the researcher obtained valuable information about common themes or issues raised by the students, about potential issues associated with teaching methods (particular methods, for example), and about the overall state of chemical teaching methods used.

After the researcher had read through all of the data, analysis via a coding process began. Coding generally means the process of organising the data into categories or concepts from which meaning can be derived (Creswell, 2012; Rossman & Rallis, 1998). These categories or themes should reveal the findings in qualitative studies. The categories or themes should be supported by specific evidence such as student interview quotes, teacher classroom examples, and so on (Creswell, 2009). The research below (results in Chapters 4 and 5) use specific examples of teacher or student behaviour or responses in drawing conclusions.

Coding by hand was performed by the researcher relative to, for example, the videotape of the classrooms, and the interviews. Categories were established on topics such as the steps used by teachers in the classroom, or for common factors influencing misconceptions, or for the correction of misconceptions.

Analysis of the coding scheme was performed by NVivo computer program for the Phase II interviews. Creswell (2009) supported the NVivo format because of its efficiency, and the ability to quickly locate similarly coded elements. NVivo offers a complete solution for rapid analysis of coding, and for visually mapping categories identified through the coding process (Creswell, 2012).

The last step is interpreting the meaning of the themes or categories. Interpreting the meaning of themes assists the researcher answer the research question while confirming or adding to past information.
The results and findings in each phase are described in detail below in Chapters 4 and 5.
CHAPTER 4
EXPLORATION OF THE USE AND EFFECTIVENESS OF THE
VisChem ANIMATIONS (PHASE I)

During Phase I, VisChem animations were applied in various classroom settings in Thailand. This chapter describes the results and findings from using VisChem animations in three studies including 1) a Pilot Study, 2) a comparison between an animation group and a non-animation group, and (3) a comparison about the use of animations in a rural school, a city school, and a university school (secondary school located on a university campus).

The researcher’s primary goal during Phase I was to evaluate the use of VisChem animations for teaching and learning chemistry in secondary school classrooms. Animations were used in classrooms to explore teaching and learning that incorporated molecular level animations in a Thai context. The results and findings from this phase were used to develop the molecular level visualisation approach for Phase II. The results from testing during Phase II, and from observations of the videotapes of teaching during Phase II, will be discussed in Chapter 5.

This research started in May, 2012, with a Pilot Study. The Pilot Study involved 39 students from the 11th Grade and one chemistry teacher. Animations were used in the classroom for the topics of states of water, and dissolving sodium chloride in water. Student performance on a drawing test was compared before and after using animations. In Study 2 (Animation/No-Animation Groups), the same topics were used for two classes with 32 students in each class from the 11th Grade. The same chemistry teacher taught both classes. One class was presented with VisChem animations, and the other class used pictures, diagrams, and ball and stick models instead of the animations. The results and findings were compared. Data were collected during June and July, 2012.
In Study 3 (University/City/Rural School Groups) VisChem animations were used in three schools in different geographic and socioeconomic areas. The students were all from the 11th Grade. Fourteen students from a university school, 13 students from a city school and 8 students from a rural school participated. The topic was the chemical processes involved in a redox reaction. Data were collected from each school between November and December, 2012.

The results of the above studies, and analysis of their test data, are described below.

4.1 STUDY 1. PILOT STUDY

The Pilot Study was used to examine whether animations assisted with student understanding, and to examine the workings of the Thai classroom both in terms of teaching and student learning. Three research questions were asked:

1. How did the teacher teach and students learn chemistry with animations?
2. Do animations help students understand chemistry concepts at the molecular level?
3. How do students’ mental models change after learning with animations?

4.1.1 Teaching and Learning with Animations

The first research question focused on how the teacher taught when using animations about the states of water and the competitive processes involved in dissolving sodium chloride in water. Data were collected from classroom video recordings. The method of data analysis from videorecording was described in Chapter 3, Section 3.6.4. Analysis focused on the teaching strategies used, and challenges found in the classroom. The details are described below.
4.1.1.1 Theme A: Teaching Strategies in Classroom

The teacher used a three-step process in the classroom: an engagement step, a teaching step and a conclusion step (see Figure 4.1).

Each part of the teaching strategy is discussed below.

(1) The engagement step

The engagement step is intended to generate interest, prompt students to access prior knowledge and connect to past knowledge, and set student focus for the instruction. The following describes observations from recorded videos of how the engagement step was done, and my critique of the effectiveness of the strategies used.

Generating interest

The teacher described the topics that would be taught, and asked questions to motivate the students. For example,

Teacher: What is the importance of the subject of chemistry?
Student1: Chemistry is related to everyday life, for example toothpaste.

The teacher explained the importance of chemistry to students. The teacher tried to relate chemistry to the day to day lives of students. For example, the teacher explained that after we eat rice or bread, the food will be digested and will change to be carbon, hydrogen and oxygen atoms. The teacher also asked questions to generate interest and to motivate the students about upcoming experiments, for example:
Teacher: Why do we have to do experiments?

Teacher (answering her own question): Because we want to know about something new to us or about something that we are curious to know.

The general goal of motivating students and asking questions about chemistry, and experiments, is certainly appropriate. However, as applied, the engagement step has probably not adequately directed the students’ attention to the three levels of thinking about chemistry. The discussion should include the three levels of thinking, even though the teacher has to be aware of overwhelming the students (Johnstone, 1991). By beginning to link the molecular level to the observable level that can be seen, heard, touched and smelled—either in everyday life or through class experiments—the process of interlinking can begin. Discussing the three levels is an important part of the “scaffolding” process, where the learner is gradually offered information just beyond the student’s competence, and where the learner can gradually assimilate and interlink the ideas (Taber, 2013).

Prior knowledge

Continuing to prompt students to engage, the teacher explained about molecules and asked the students questions about molecules. The teacher tried to explain what the molecular level was, and asked questions about the molecular level. Below is a representative exchange between the teacher and students in the classroom where the teacher tries to get students to access prior knowledge:

Teacher: A molecule is thing that we have never seen before, and the model can help us better understand from abstract areas.

Teacher: Can you give examples of things that we have never seen?

Students: Atoms, cells and air.

As noted during the engagement step discussion, to this point the teacher had still not explicitly discussed the three thinking levels. Arguably the groundwork for discussions about the molecular level had not been fully or adequately explained. In other words, prior knowledge must be appropriately linked with new knowledge, otherwise the teacher runs the risk of overloading the students’ working memories (Johnstone, 1992).
(2) Teaching step

Following the engagement step, the teacher taught the topics of states of water and dissolving sodium chloride in water in three parts. The students did laboratory work, then drawings, and after completing drawings viewed an animation.

Laboratory

Students were divided into four to five mixed gender groups. Beakers, test tubes, salt and ice were provided for each group. There were three experiments for this class including 1) observing liquid water, 2) observing ice, and 3) observing how water dissolves salt.

In the first experiment, the teacher instructed students to pour water into the beaker, and to observe the physical properties of water such as being colourless. In the second experiment, students observed the ice in the beaker, and wrote the physical properties such as ice can float in water. During the last experiment, students wrote the physical properties observed when water was added to a test tube to dissolve solid sodium chloride.

Student drawings

After students completed each experiment, they were asked to draw molecular level representations of what was occurring. The video recordings revealed that many students were confused and experienced difficulties drawing at the molecular level. Many students asked the teacher “How can I draw?” and the teacher responded: “You can draw whatever you believe in your mind to be accurate.” The students had never been taught how to draw at the molecular level. Nevertheless, students tried to draw the chemical species involved based on their imagination.

Viewing the animations

Immediately following the laboratory work and the student drawings, the teacher presented the animations to students by projecting the animations on a screen in front of the room. Some sample animations can be found in Figure 2.6 or Figure 2.7 in Chapter 2. During the presentation of each animation, the teacher was asking the students questions about, and explaining, the on-screen animation. However, the
teacher did not focus on the key features in the animations, such as the arrangement of ions in the salt crystals, or the behaviour of the ions at the molecular level, such as their vibrating in a fixed position. The following exchange is representative:

*Teacher:* What is the state of salt?
*Students:* Solid.
*Teacher:* What is the colour of salt?
*Students:* Green and grey.

The teacher’s question about the colours of the salt crystals in the animation could have been misleading. Students might have thought that green and grey represent the actual colour of sodium chloride. Of course, the green and grey colours were merely colours chosen for demonstrative purposes to differentiate sodium ions and chloride ions.

3) Conclusion step

The teacher asked students from each group to present their work in front of the classroom. Most of the student presentations did not, however, address or examine the molecular level in ice. Sample presentation statements and questions are below:

*Group 1*
*Student 1:* The volume of water in a liquid state has not changed, and the water is colourless.
*Student 2:* Molecules in ice are close together.
*Teacher:* How many hydrogen and oxygen atoms are in a water molecule?
*Student 1:* Hydrogen 2 atoms and oxygen 1 atom.

*Group 2*
*Student 3:* Water is colourless, and has no smell. Water consists of hydrogen and oxygen. Ice floats in water.

After the two groups presented their ideas on the states of water, the teacher did not conclude and explain to students about how the arrangement or behaviour of water molecules in liquid and ice are different. The teacher also did not explain...
about the key features of the animation of water in a liquid state and a solid state. For example, the teacher did not highlight that molecules of water in a solid state can vibrate in a fixed position, or that there are spaces between molecules of water in a solid state.

4.1.1.2 Theme B: Preliminary Observations about Teaching and Learning Chemistry in the Classroom with Animations

The video recordings of classroom instruction using animations to portray molecular level events revealed some potential problem areas in how the instruction was conducted. Primarily, the problems related to possible teacher misconceptions. However, classroom presentation factors such as the technical quality and volume of the audio, and narration in English language, almost certainly contributed to the generation of, or failure to dispel, student misconceptions. Finally, the students’ prior knowledge should be considered as they had not previously been exposed to molecular level concepts. These three aspects—teacher knowledge, presentation factors, and student prior knowledge—are elaborated upon below (see Figure 4.2).

![Figure 4.2 Overview of potential problem areas in chemistry instruction](image)

**Teacher Knowledge**

The teacher displayed apparent misconceptions about many aspects of the chemistry topics. Teacher-student exchanges on five topics are mentioned below as representative examples where the instruction may have been misleading in one or more respects.
• Misconception One: Relative separation of water molecules in liquid water and ice

The teacher explained the difference between the relative separation of molecules in liquid water and in ice as follows:

Teacher: Molecules of water in a solid state will be close together, which is different from molecules of water in a liquid state that we saw from the animation.

The space between molecules of water in the solid state is larger than that in the liquid state, but the teacher’s statement did not make this clear.

• Misconception Two: Relative weights of molecules of water in the liquid and gas states

The teacher tried to explain the difference of weight between liquid and gas by using an analogy of stone (heavy) and cotton (light) to students. However, in the process, the teacher displayed some further misconceptions:

Teacher: A stone is heavy and cannot move but cotton is light, the same as molecules of gas that can blow. However, water cannot blow.

In fact, the weight of a molecule of water in the solid, liquid and gas states is the same.

• Misconception Three: Confusion about the term “steam”

The teacher tried to explain what was happening when water boiled while a video was being presented to the students:

Teacher: When water is boiling, you can see the bubbles. The steam will move through the liquid and after that will change to be a gas state. A molecule of water in a gas state will have more separation than water molecules in a liquid state.
The teacher apparently did not realise that steam, and water molecules in the gas state, are the same thing

- Misconception Four: Confused use of the terms ion, atom and molecule
  After salt is melted, Na\(^+\) and Cl\(^-\) ions are separated from each other without water.

  *Teacher:* Green refers to chloride. Grey refers to sodium.
  *Teacher:* A molecule of sodium combined with a chlorine ion.

  The teacher said a “molecule of sodium,” but did not say sodium ion, and said “chlorine ion,” but did not say chloride ion. The teacher appears to confuse the terms and nomenclature of molecules, atoms, and ions.

- Misconception Five: Solution and liquid
  The teacher may have been confused about the difference between solution and liquid:

  *Teacher:* When we added salt in water, do you still see salt?
  *Students:* No.
  *Teacher:* Where is the salt?
  *Teacher:* Water will make the particles of salt separate from each other and after that it will become a liquid.

  In fact, dissolving sodium chloride in water is in an aqueous state, not a liquid state.

  From the video recording we can see that the teacher did not ask probing questions, and did not focus students on the relevant key features. For example, for dissolving sodium chloride in water, the key features are that the sodium ions and chloride ions are separated from each other, and each ion is surrounded by water molecules. The teacher did not identify these key features prior to the video recording being shown to the students.
The teacher also did not follow-up after the laboratory, or after the presentation of animations, with probing questions to test deep understanding. After students observed the ice in water during a laboratory experiment, for example, the teacher asked general questions that would not tend to reveal whether students had a firm understanding of the underlying molecular concepts:

*Teacher:* Does the ice float on liquid water?
*Students:* Yes, it does.

The teacher should present questions that tend to elicit the use of higher order thinking skills such as: “Why or how does ice float on the liquid water?” To answer such a question, a student would have to understand that the ice can float on liquid water because the space between molecules of water in the solid state is larger than in the liquid state.

When presenting the animation showing solid sodium chloride, the teacher did not ask questions or point out key features to probe or develop a deep understanding. Below is a typical exchange that focused on the colour of salt rather than on an understanding of molecular level chemistry at a deeper level:

*Teacher:* What is the state of salt?
*Students:* Solid.

*Teacher:* What is colour of salt?
*Students:* Green and grey.

The teacher should perhaps ask questions to help students obtain a deeper understanding at the molecular level such as: “If the temperature was increased, what would happen to the ions in the crystalline salt?” Such a question would require students to consider molecular level events. Specifically, the students would have to consider that after the temperature was increased, the ions in the crystal will be vibrating faster until they can start moving out of their average positions in space, and move relative to one another.
The main, apparent problem was that the teacher did not point out the key features to students. For example, in the melting of solid sodium chloride, there are three main key features in the animation:

1. Vibration of the ions around fixed positions in the solid state;
2. The Na\(^+\) and Cl\(^-\) ions are slightly more separated from each other, and can move past one another;
3. Melting does not involve water.

Drawing student attention to these key features can help students to “focus on the essential message” (St Clair-Thompson et al., 2010, p. 137). Absent such advance guidance, students may be unable effectively to process the information they are receiving in the animation.

**Presentation Factors**

When the teacher initially presented the animations in the classroom, the students seemed interested in animations. However, the sound from the audio speaker was not loud enough. Problems with sound create an obvious impediment. When the sound is not clear, the students may pay less attention to the animations. In addition, the animations were in English. Although the teacher was trying to explain and teach students in Thai language, the English narration may have been difficult or distracting to the students on topics like vibration, melting and dissolving. Furthermore, the explanations from the animation itself were fast for students to follow.

Researchers have identified the need for repeating animations for best effect (Tasker & Dalton, 2006). I recommend that in similar circumstances, the sound be turned off and the teacher provides the narration, with frequent stoppages.

**Student Prior Knowledge**

At this stage in the Thai chemistry curriculum, students normally have not been taught chemistry at the molecular level or, if they have received such teaching, there is likely no explicit or developed link to the other levels. Students normally see only diagrams or pictures at the molecular level from a textbook. The results are not
surprising: the video recording revealed that it was difficult for the students to draw and explain at the molecular level.

It is important that before teaching and learning chemistry at the molecular level, the teacher and students should be guided and trained how to think at the molecular level, and students need guidance about how to draw accurate representations of their mental models. In essence, students need to learn the language of chemistry so that they may effectively speak that language (Sirhan, 2007).

4.1.2 Learning Outcomes

The observations above relate to issues with presentation of animations in general. The researcher next examined whether animations could help students understand chemistry concepts at the molecular level.

The learning outcomes are discussed below in two parts: students’ understanding and their mental model change. Students’ understanding and their mental model changes were ascertained by analysing a student drawing and explanations test. The drawings and questions test was checked by a professor who has over 10 years’ experience with teaching university level and by a chemistry teacher with 17 years’ experience teaching chemistry in secondary schools.

The drawings and questions test was used to analyse the learning outcome based on understanding as measured by examining total scores by topic and key feature, and mental model change as measured by comparing pre-test responses to post-test responses.

For all three studies in Phase I, a pre-test was administered to the students before any teaching occurred. A post-test was administered using the same questions, and was given immediately after conclusion of the teaching on a given topic.

For understanding, a paired-sample t-test was applied. The total mean score of pre-test and post-test was used to analyse whether, after learning with the
animations, students could have a better understanding than before learning with the animations. Mental model change was checked by comparing the number of students that had correct pre-test and post-test scores in each key feature. The test for this study is shown in Appendix E.

The results and findings on the topics of states of water, and dissolving sodium chloride in water, are described below.

4.1.2.1 Student Understanding

A paired-samples t-test was used to compare the mean pre-test and post-test scores in the same group, as presented in Table 4.1.

Table 4.1  
Comparison of means of pre-test and post-test scores before and after using animations

<table>
<thead>
<tr>
<th>Test</th>
<th>N</th>
<th>M</th>
<th>SD</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-test</td>
<td>39</td>
<td>0.90</td>
<td>0.64</td>
<td>-10.53</td>
<td>.00*</td>
</tr>
<tr>
<td>Post-test</td>
<td>39</td>
<td>2.59</td>
<td>0.88</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p < .05, one-tailed

The paired-samples t-test was conducted to compare the overall score on questions probing understanding at the molecular level before and after seeing the animations. There was a statistically significant increase from the pre-test score ($M = 0.90$, $SD = 0.64$) to the post-test score ($M = 2.59$, $SD = 0.88$); $t(38) = -10.53$, $p = .00$).

Table 4.1 displays the overall test results obtained from the 39 students. The progress from pre-test to post-test can also be analysed with reference to particular key features described below, and these are presented in Table 4.2. The benefit of looking at each key feature is that it indicates what students learn in the topics covered.
Table 4.2

*The percentage change from pre-test to post-test score on test items referring to specific key features in the animations.*

<table>
<thead>
<tr>
<th>Items</th>
<th>Key Features</th>
<th>Percentage Correct Pre-test (N=39)</th>
<th>Percentage Correct Post-test (N=39)</th>
<th>Percentage Change from Pre-test to Post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The H and O atoms in each water molecule have different sizes</td>
<td>0(0)</td>
<td>87 (34)</td>
<td>+87 (+34)</td>
</tr>
<tr>
<td>2</td>
<td>Water molecules in liquid move</td>
<td>69 (27)</td>
<td>74 (29)</td>
<td>+5 (+2)</td>
</tr>
<tr>
<td>3</td>
<td>Water molecules in ice vibrate in a fixed position</td>
<td>21 (8)</td>
<td>46 (18)</td>
<td>+25 (+10)</td>
</tr>
<tr>
<td>4</td>
<td>When NaCl(s) melts, Na⁺ and Cl⁻ ions separate slightly without any involvement of water molecules</td>
<td>0 (0)</td>
<td>28 (11)</td>
<td>+28 (+11)</td>
</tr>
<tr>
<td>5</td>
<td>When solid sodium chloride dissolves in water, Na⁺ and Cl⁻ ions are separated from each other as hydrated ions</td>
<td>0 (0)</td>
<td>23 (9)</td>
<td>+23 (+9)</td>
</tr>
</tbody>
</table>

*Note:* The number in brackets ( ) is the number of students with correct answers

Analysis of the scores on pre-test and post-test questions on each of the five key features is described below.

**Key Feature 1.** Hydrogen and oxygen atoms in each water molecule have different sizes.

Students were asked to draw water molecules to probe their mental models of the relative sizes of the H and O atoms in, and the shape of, a water molecule. None of the 39 students could accurately draw a molecule of water where each H atom is smaller than the O atom. Students drew only a single circle to show a water molecule, rather than depicting the two hydrogen atoms and the oxygen atom.

After seeing the representations of water molecules of water in the animation, 34 students (87%) were able to draw a representation of a water molecule with appropriate relative sizes of atoms, and a bent shape.
Key Feature 2. Water molecules in liquid move.

Students were asked to write and explain whether water molecules in a liquid state can move or not. Before seeing the animation, 27 (69%) students could answer this question correctly. After seeing the animation, 29 students (74%) correctly responded. The results suggested that students had a slightly better understanding in this key feature after learning with the animation.

Some confusion remained among the students even after seeing the animation. More than 50% of the students wrote “liquid water” can move, instead of “water molecules” in a liquid state can move.

Key Feature 3. Water molecules in ice vibrate in a fixed position.

Students were asked to write and explain whether water molecules in ice vibrate in a fixed position. Eight students (21%) correctly answered this question. After seeing the animation depicting water molecules in ice, 18 students (46%) correctly responded to the previous question on this key feature, a 25% increase. Nevertheless, more than 50% of the students had not learned this key feature.

Key Feature 4. When NaCl(s) melts, Na\(^+\) and Cl\(^-\) ions separate slightly without any involvement of water molecules.

Students were asked to draw the arrangement of particles after sodium chloride melts. Before viewing the animation, none of the students could provide a correct drawing. More than 50% students drew only the circles to show the sodium ions and chloride ions. Interestingly, more than 50% of the students did not draw the ions being separated from each other (to be sure, the separation is not large, but the separation should still be shown). After students viewed the animation, 11 students (28%) correctly showed that the sodium ions and chloride ions are separated from each other without water. More than half of the students drew sodium and chlorine atoms separated from each other instead of sodium ions and chloride ions. This suggests that these students thought that NaCl (s) was composed of Na and Cl atoms, not ions, or had other misconceptions about atoms and ions.

Key Feature 5. When solid sodium chloride dissolves in water, Na\(^+\) and Cl\(^-\) ions are separated from each other as hydrated ions.
Students were asked to draw the arrangement of the particles after solid sodium chloride dissolved in water. In the pre-test, all of the student drawings showed sodium chloride linked together where the sodium ion and chloride ion are closely packed and are not separated from each other. After seeing the sodium chloride dissolving animation, in the post-test 9 students (23%) drew an acceptable arrangement of the particles with the sodium ions and chloride ions separated from each other, and surrounded by water molecules.

### 4.1.2.2 Mental Model Change

The third research question during the Pilot Study asks whether students changed their mental model after instruction and viewing animations. Data from students’ drawings and explanations gathered from their pre-test and post-test responses were used to determine if student mental models had changed. The mental model change described in this section compares individual student responses pre-test to their responses post-test with reference to particular key features. The results are described below.

Table 4.3

<table>
<thead>
<tr>
<th>Key Feature</th>
<th>//</th>
<th>/X</th>
<th>XX</th>
<th>X/</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>13 (5)</td>
<td>87 (34)</td>
</tr>
<tr>
<td>2</td>
<td>56 (22)</td>
<td>13 (5)</td>
<td>13 (5)</td>
<td>18 (7)</td>
</tr>
<tr>
<td>3</td>
<td>8 (3)</td>
<td>13 (5)</td>
<td>41 (16)</td>
<td>38 (15)</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>72 (28)</td>
<td>28 (11)</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>0</td>
<td>77 (30)</td>
<td>23 (9)</td>
</tr>
</tbody>
</table>

*Note: The number in the brackets ( ) refers to the number of students who displayed a mental model change.*

Key:  
// = correct answer both pre-test and post-test  
/X = correct answer pre-test and incorrect answer post-test  
XX = incorrect answer both pre-test and post-test  
X/ = incorrect answer pre-test and correct answer post-test
Table 4.3 shows the percentage and number of students who responded to seeing the animations in each of four ways: 1) students have a correct mental model before and after seeing the animations; 2) students have a correct mental model before seeing the animations, but afterwards students have an incorrect model (one or more); 3) students have an incorrect mental model before seeing the animations, and afterwards still have an incorrect model (one or more); 4) students have an incorrect mental model before seeing the animations, and afterwards demonstrate that they have a correct mental model.

Mental model change is further categorised according to five key features as they relate to the topics of water and dissolving sodium chloride in water.

**Key Feature 1:** Hydrogen and oxygen atoms in each water molecule have different sizes.

A water molecule consists of two atoms of hydrogen and one atom of oxygen. An oxygen atom is bigger than a hydrogen atom.

Table 4.3 shows five students (13%) did not draw the bonded atoms in water molecules in the pre-test or the post-test (see Figure 4.3). These students did not demonstrate that they had learned this feature of the atoms in a water molecule.

![Before](image1)

![After](image2)

*Figure 4.3. Sample of a drawing of water molecules before and after viewing the animation, failing to demonstrate that they had learned this feature of the atoms in a water molecule.*

Most students did demonstrate that they understood this feature of water molecules after viewing the animation. Thirty-four students (87%) initially drew inadequate drawings, but drew correct depictions after viewing the animation.
Representative student diagrams are shown below with correct explanations (see Figures 4.4 and 4.5). Student drawings revealed that before viewing the animation, students had misconceptions about the size of hydrogen and oxygen atoms and about the shape of the molecule of water. However, after seeing the animation, many students could draw the water molecule correctly—the water molecule with two atoms of hydrogen and one atom of oxygen, and the atom of oxygen larger than the hydrogen atom.

One explanation for the network of circles and lines drawn in Figures 4.4 and 4.5 is that they were copying the physical ball-and-stick model of water in the classroom.

Before | After
--- | ---

*Figure 4.4.* A student drawing of a “molecule of water” before and after viewing the animation

Before | After
--- | ---

*Figure 4.5.* A student drawing of a “molecule of water” before and after viewing the animation

**Key Feature 2:** Water molecules in liquid water move.

Twenty-two students (56%) gave the correct answer on this key feature in both the pre-test and the post-test. That high, positive result suggested that students already understood this key feature. However, some students still had misconceptions between water—the substance—in its liquid state moving, and water
molecules in liquid water moving. Explanations provided by students revealed that the students seemed to confuse water in a liquid state flowing—an observable event—with the behaviour of water molecules in a liquid.

Five students (13%) who correctly answered the question in the pre-test answered it incorrectly in the post-test. Another five students (13%) had misconceptions both before and after using the animation. Only seven students out of 39 (18%) changed from incorrect to correct responses.

**Key Feature 3:** Water molecules in ice vibrate in a fixed position.

Three students (8%) gave correct answers to the question on this feature in both the pre-test and in the post-test, and five students (13%) who answered correctly in the pre-test answered incorrectly in the post-test. Sixteen students (41%) had misconceptions both before and after seeing the animation.

The results suggested that the animation could not help students better understand about molecules in ice vibrating in a fixed position. The teacher might consider spending more time explaining this key feature to students, and might consider showing the animation twice. Clearly a large percentage of the students still had difficulty with this key feature even after learning with the animation. This may be attributed to the various problems that were discussed in Section 4.1.1.2. However, 15 students (38%) had incorrect pre-test responses and correct post-test responses. The animation therefore appears to have helped some students better understand at the molecular level.

**Key Feature 4:** When NaCl(s) melts, Na\(^+\) and Cl\(^-\) ions separate slightly without any involvement of water molecules.

Key Feature 4 test results are shown in Table 4.3. Twenty-eight students (72%) had incorrect answers both pre-test and post-test. Students therefore still had misconceptions about melting of sodium chloride even after seeing the sodium chloride melting animation. Only 11 students displayed improvement after seeing the animation.
Sample student misconceptions about sodium chloride melting are revealed in their written test responses:

“Dissolving and melting are the same”

“Dissolving is the process of solid turning to liquid but melting is liquid becoming gas”

“When we heat the temperature up the salt is melting, and then it will dissolve to be water”

“Salt is melting to be solid”

“Melting uses water in the process”

“Melting cannot separate Na\(^+\) and Cl\(^-\) from each other but dissolving can separate the ions”

“Melting is the process of liquid changing to be gas, but dissolving is solid changing to be liquid”

The misconceptions mentioned above might arise from the interchangeable use of the terms “dissolving” and “melting.” The teacher suggested that the terms were synonymous when she said that “the topic that we will learn is melting, or what we call dissolving.”

**Key Feature 5:** When solid sodium chloride dissolves in water, Na\(^+\) and Cl\(^-\) ions are separated from each other as hydrated ions.

Thirty students (77%) had incorrect answers both in the pre-test and in the post-test. Students therefore still had misconceptions about dissolving sodium chloride in water before and after seeing the sodium chloride dissolving animation (see Figure 4.6).

![Figure 4.6](image-url)

*Figure 4.6.* Sample student drawing of sodium chloride solution before and after viewing the animation
Nine students (23%) produced better drawings of sodium chloride solution after seeing the animation (see Figures 4.7 and 4.8). Students could draw the Na$^+$ and Cl$^-$ ions separated from each other with each ion surrounded by water molecules.

![Before](image1.png) ![After](image2.png)

*Figure 4.7. Sample student drawing of dissolved sodium chloride in water before and after viewing the animation*

![Before](image3.png) ![After](image4.png)

*Figure 4.8. Another sample student drawing of dissolved sodium chloride in water before and after viewing the animation*

4.2 STUDY 2. COMPARISON OF CHEMISTRY STUDENT PERFORMANCE WITH AND WITHOUT SEEING ANIMATIONS

The aim of Study 2 was to evaluate teaching and learning chemistry by comparing a class that viewed the VisChem animations to a class that did not. Two classes with 32 students in each class were taught by the same chemistry teacher. The topics used were the same as for the Pilot Study: states of water, and dissolving sodium chloride in water. This study examined the following three questions:

1. How did the teacher teach and students learn about the states of water and dissolving sodium chloride in water, with and without animations?

2. Do students who participate in the animation group have a better understanding at the molecular level than students who did not see the animations?
3. How do students’ mental models change after viewing animations?

The results and findings are described below.

4.2.1 Teaching Strategies

The first research question in Study 2 asks how teaching chemistry occurs in the topic of states of water and dissolving sodium chloride in water, with and without animations. Thirty-two students in each of two groups—one viewing animations, the other not—were taught with the same chemistry teacher, and both sessions were recorded on video.

Data analysis of the two video recordings found four teaching strategies were used during the teaching step (as distinct from the engagement or conclusion steps): observing, drawing, discussing, and viewing.

<table>
<thead>
<tr>
<th>Categories</th>
<th>Animation Group</th>
<th>Non-Animation Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teaching strategies</td>
<td>1. Observing</td>
<td>1. Observing</td>
</tr>
<tr>
<td></td>
<td>2. Drawing</td>
<td>2. Drawing</td>
</tr>
<tr>
<td></td>
<td>3. Discussing</td>
<td>3. Discussing</td>
</tr>
<tr>
<td></td>
<td>4. Viewing</td>
<td>4. Viewing</td>
</tr>
<tr>
<td>Tools</td>
<td>Animations</td>
<td>Pictures, diagrams, ball and stick models</td>
</tr>
</tbody>
</table>

The teaching strategies differed primarily in that step number 4, viewing, would incorporate animations in one classroom, but not in the other, depending on the topic. The class that did not view animations was encouraged to visualise the molecular level using graphics in the textbook, diagrams, and ball and stick models.

Each class was taught the same two chemistry topics—states of water and dissolving sodium chloride in water—by the same teacher. A cross-over experimental design was used. Thus, if Classroom A was taught a topic using an animation, the same topic would be taught in Classroom B without an animation. For the other topic, Classroom A would not view the corresponding animation, and
Classroom B did. In both classrooms, one topic would be taught with an animation, and one topic without an animation.

Table 4.5 shows the cross-over experimental design for the two classes to cancel out any effect associated with the different groups of students.

Table 4.5
Cross-over experimental design used in Study 2

<table>
<thead>
<tr>
<th>Topic</th>
<th>Group A</th>
<th>Group B</th>
</tr>
</thead>
<tbody>
<tr>
<td>States of water</td>
<td>Animations</td>
<td>No Animations</td>
</tr>
<tr>
<td>Dissolving sodium chloride in</td>
<td>No Animations</td>
<td>Animations</td>
</tr>
<tr>
<td>water</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Teaching States of Water Topic – Animation Group

The 32 students were divided into mixed gender groups of roughly five to six students per group. At the engagement step, to generate interest, the teacher prompted students to access and connect prior knowledge by asking questions targeted at topics covered during prior chemistry instruction. Below are some examples of how the teacher engaged the students by asking questions about topics covered in prior classes:

Teacher: What is the formula of water?

Students: H₂O

The teacher explained the structure of water molecules to students by drawing molecules of water on a whiteboard. By this year in school, this topic would have already been covered in prior instruction. The teacher asked students about their prior knowledge on the states of water:

Teacher: How many states of water exist?

Students: Three states: solid, liquid and gas.

After the conclusion of the engagement step, a four-step teaching strategy was used, and is described below in each step.
Step 1: Observing

The teacher asked students to observe water in the beaker and asked students questions about their observations. For example:

*Teacher*: If we look at water in the beaker, describe or imagine the arrangement of molecules of water?

After observing water in a beaker, the teacher asked students to explain the observable properties of water in a liquid state. Students observed and wrote the properties of water in a liquid state like the water being colourless, or being able to pour water from one beaker to another beaker. Within each group, students discussed their observations.

Step 2: Drawing

The teacher asked students to draw molecules of water in a liquid state using paper and pencil. Students in each group also were allowed to freely talk with each other, to compare drawings, and thereby to help each other to draw the structure of molecules of water in the liquid state.

Step 3: Discussing

After students in each group wrote about the observable properties of liquid water, and drew the arrangement of water molecules in the liquid state on the whiteboard, the teacher then asked students which group had drawn the molecules of water in a liquid state correctly. When drawing on the whiteboard, students in each group were allowed to discuss what the diagram should look like. After these preliminary discussions, the teacher asked students about the molecular level, and later provided the explanation:

*Teacher*: Describe the arrangement of water molecules in the liquid state?

*Teacher*: The arrangement of water molecules in the liquid state has a larger space than water molecules in a solid state.  

Note that the answer the teacher provided to students was incorrect because it suggested that there was a larger space between water molecules in a solid state.
Step 4: Viewing

The teacher showed the animation by projecting the animation on the screen in front of the room to the students. While viewing the animation, the teacher explained the properties of water at the molecular level to students. However, the teacher did not pause her demonstration of the animation in order to explain each key feature of the animation.

Teaching States of Water Topic – Non-Animation Group

During the preliminary engagement step, the teacher asked the same questions in this group as had been asked to the animation group. The teacher assessed prior knowledge by asking “What is the formula of water?” or “How many states of water exist?” The teacher drew a water molecule on a whiteboard, and explained that a water molecule consists of one oxygen atom and two hydrogen atoms. The oxygen atom is larger than the hydrogen atoms. The teacher asked more questions to stimulate students’ higher order thinking skills such as “Explain the arrangement of water molecules in the three states of water.” The 32 students were divided into mixed gender groups with around 5 to 6 students in each group.

The teacher used the same four-step teaching strategy used with the animation group:

Step 1: Observing

The teacher asked students to observe the physical properties of water in a liquid state. Students poured water from one beaker to another beaker and observed. After that observation, students in each group presented the physical properties of water in a liquid state orally in front of the classroom.

Step 2: Drawing

Students were asked to draw the arrangement of water molecules in a liquid state using paper and pencil, and then students in each group presented the drawing of the arrangement of water molecule in a liquid state in front of the classroom on a whiteboard.
Step 3: Discussing

The teacher and students discussed the structure of water molecules in a liquid state by using and comparing the pictures and diagrams that students in each group drew on the whiteboard. The teacher guided students with questions about the pictures and diagrams by asking questions such as “When we pour water from one beaker to another beaker, why does the water flow from beaker to beaker?” Students answered “Because it is a liquid.” The teacher then explained—although not correctly—that “water can flow because of the hydrogen bond in water molecules.”

Step 4: Viewing

During the viewing step, the teacher used a ball and stick model to explain about the shape of a water molecule:

Teacher: You can see from a ball and stick model that a water molecule has a bent shape.

The teacher also used pictures and diagrams from a textbook to explain about the arrangement of water molecule in a liquid state. During presentation of these various visualisations, the students could not see how water molecules in a liquid state move because the models were static.

4.2.2 Learning Outcomes

The learning outcomes are discussed below in two parts: students’ understanding as measured by an independent sample t-test, and their mental model change where pre-test and post-test results are compared.

Students’ understanding and their mental model changes were ascertained by analysing the results from a drawing and explanation test. For both sodium chloride and the states of water, there were six drawing and explanation test questions presented (see Appendix E). The questions were checked by the same two educators who helped develop the Pilot Study questions.
The mean scores of the tests from the two topics were analysed by using an independent sample t-test to compare the student understandings in the animation group and the non-animation group. In addition, the total number of students who had correct post-test responses in each key feature was compared between groups to assess relative understanding.

To analyse mental model change, the pre-test and post-test responses in each group were compared in each key feature.

The results and findings with the topics of states of water, and dissolving sodium chloride in water, are described separately below.

4.2.2.1 Student Understanding

To answer the second research question, scores in the pre-test and in the post-test, and in each key feature, were analysed. A quantitative method using an independent samples t-test was used to compare chemistry students’ relative performance in the two classes (animation group, and non-animation group). The two topics of states of water, and dissolving sodium chloride in water, are analysed and explained separately below.

States of Water

Table 4.6 below compares the mean of pre-test and post-test scores between the animation group and non-animation group. The independent samples t-test was conducted to compare the post-test score of understanding the states of water at the molecular level between the animation and non-animation groups. The post-test mean score for the animation group was significantly higher ($M=3.60, SD=1.36$) than the non-animation group ($M=2.66, SD=0.90$), $t(62) = 3.47, p = .00$. The results suggested that after learning with the topic of states of water, students from the animation group could better understand chemistry concepts at the molecular level than students who learned chemistry from the non-animation group.
Table 4.6

*Compare mean of the post-test score between classes with and without animation*

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>M</th>
<th>SD</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animation</td>
<td>32</td>
<td>3.66</td>
<td>1.36</td>
<td>3.47</td>
<td>.00*</td>
</tr>
<tr>
<td>Non-Animation</td>
<td>32</td>
<td>2.66</td>
<td>.90</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p < .05, one-tailed

Student responses have also been analysed with reference to particular key features. The benefit of looking at individual key features is that the results reveal greater detail about what the students either learned, or did not learn, when presented with the animations compared to learning without the animations.

Table 4.7

*Compare percentage of students who had correct post-test answers between the groups with reference to key features*

<table>
<thead>
<tr>
<th>Items</th>
<th>Key Features</th>
<th>Percentage of Students</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Animation group (N=32)</td>
</tr>
<tr>
<td>1</td>
<td>Correct model of a molecule of water</td>
<td>56.25</td>
</tr>
<tr>
<td>2</td>
<td>Bent shape</td>
<td>84.38</td>
</tr>
<tr>
<td>3</td>
<td>Different size atom of H and O</td>
<td>59.38</td>
</tr>
<tr>
<td>4</td>
<td>Water molecules in liquid move</td>
<td>100</td>
</tr>
<tr>
<td>5</td>
<td>Structure lattice in ice (arrange neatly, space)</td>
<td>56.63</td>
</tr>
</tbody>
</table>

**Key Feature 1:** Correct model of a molecule of water.

Students in both groups were asked to draw a molecule of water to assess their understanding of the model of a water molecule that has a bent shape, and different sized atoms of hydrogen and oxygen. Fifty-six percent of students in the animation group could draw a model of a molecule of water correctly, compared to 34.38% of students in the non-animation group. The results suggested that students from the animation group understood this key feature better, although there were only slight differences in the actual number of students who correctly answered between the two groups (Animation group =56.25, Non-Animation group=34.38).
**Key Feature 2:** Bent shape.

A molecule of water has a bent shape. After students drew the molecule of water for Key Feature 1, a correct model of a water molecule can be shown with reference to the shape of the molecule of water. Eighty-four percent of students in the animation group could draw the molecule of water with a bent shape. Interestingly, 100% of students in the non-animation group drew the bent shape of a molecule of water correctly.

**Key Feature 3:** Different sized atoms of hydrogen and oxygen.

In a molecule of water, the size of a hydrogen atom is smaller than an atom of oxygen. Both groups were asked to draw a molecule of water. Fifty-nine percent of students in the animation group could draw the atoms correctly, while only 28.1% of students from the non-animation group could.

**Key Feature 4:** Water molecules in a liquid state move.

Students were asked to write and explain whether water molecules in a liquid state can move. In both groups, all students answered correctly. However, many students still had a misconception about water molecules in a liquid state and water in a liquid state.

Similar to students in the Pilot Study, the students in Study 2 confused the physical properties of water with the molecular properties. The question asked students about the properties of a water molecule at the molecular level in a liquid state. The question did not ask about the physical property of water in a liquid state. Even though the question clearly required consideration of properties of water at the molecular level, many students explained that a water molecule in a liquid state can move because water can be poured from beaker to beaker.

**Key Feature 5:** Structure lattice in ice (regular arrangement in space, vibrating in fixed positions).

To assess student understanding of the structure lattice in ice, students were asked to draw the arrangement of molecules of water in a solid state. Fifty-six percent of students in the animation group provided accurate visual representations, while none of the students from the non-animation group did.
Dissolving Sodium Chloride in Water

Table 4.8 below compares the mean of the post-test scores between the animation group and the non-animation group. An independent samples t-test was conducted to compare the pre-test and post-test score of understanding at the molecular level for dissolving sodium chloride in water.

The post-test mean score from the animation group was significantly lower ($M=2.69$, $SD=1.40$) than the non-animation group ($M=3.31$, $SD=0.99$), $t(62) = -2.06$, $p = .02$.

Table 4.8

*Compare the mean of the post-test scores between the animation and non-animation groups*

<table>
<thead>
<tr>
<th>Group</th>
<th>$N$</th>
<th>$M$</th>
<th>$SD$</th>
<th>$t$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animation</td>
<td>32</td>
<td>2.69</td>
<td>1.40</td>
<td>-2.06</td>
<td>.02*</td>
</tr>
<tr>
<td>Non-Animation</td>
<td>32</td>
<td>3.31</td>
<td>0.99</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p < .05, one-tailed

Table 4.8 describes overall post-test results between the groups. Table 4.9 focuses on results with reference to key features. The results are described below.

Table 4.9

*Compare percentage of students with correct post-test answers between the groups with reference to key features*

<table>
<thead>
<tr>
<th>Items</th>
<th>Key Features</th>
<th>Percentage of Students</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Animation group (N=32)</td>
</tr>
<tr>
<td>1</td>
<td>Size of Na$^+$ smaller than Cl$^-$</td>
<td>59.39</td>
</tr>
<tr>
<td>2</td>
<td>Na$^+$ and Cl$^-$ are closely packed in solid sodium chloride</td>
<td>62.50</td>
</tr>
<tr>
<td>3</td>
<td>In melted sodium chloride, the ions are not so closely packed, and water molecules are not involved</td>
<td>28.13</td>
</tr>
<tr>
<td>Items</td>
<td>Key Features</td>
<td>Percentage of Students</td>
</tr>
<tr>
<td>-------</td>
<td>------------------------------------------------------------------------------</td>
<td>------------------------</td>
</tr>
<tr>
<td>4</td>
<td>Correct model of dissolving NaCl in water (Hydration of ion)</td>
<td>31.25</td>
</tr>
<tr>
<td>5</td>
<td>In sodium chloride solution, Na(^+) and Cl(^-) are separated from each other</td>
<td>87.50</td>
</tr>
</tbody>
</table>

**Key Feature 1:** Size of Na\(^+\) smaller than Cl\(^-\).

To assess students’ understanding of the size of ions in sodium chloride, students were asked to draw the structure of sodium chloride in a solid state. Fifty-nine percent of students in the animation group could draw the structure of sodium chloride in a solid state correctly with the size of Na\(^+\) being smaller than Cl\(^-\), while only 9.38% of students in the non-animation group could.

**Key Feature 2:** Na\(^+\) and Cl\(^-\) are closely packed in solid sodium chloride.

To assess students’ understanding of the arrangement of ions in sodium chloride being closely packed, students were asked to draw the structure of sodium chloride in a solid state. The percentage of students who could draw the structure of sodium chloride correctly from the animation group was 62.50%, compared to 87.50% in the non-animation group.

**Key Feature 3:** In melted sodium chloride, the ions are not so closely packed, and water molecules are not involved

Students were asked to draw the arrangement of the particles when sodium chloride is melting. Twenty-eight percent of students from the animation group did so correctly, compared to 84.35% in the non-animation group. The results suggested that students from the non-animation group had an overall better understanding that when sodium chloride is melting, the sodium ions and chloride ions are separated from each other without water.

**Key Feature 4:** Correct model of dissolving NaCl in water (hydration of ion).

Students were asked to draw the arrangement of particles from dissolving sodium chloride in water. Thirty-one percent in the animation group could draw the arrangement correctly, compared to 56.25% of students in the non-animation group.
Key Feature 5: In sodium chloride solution, Na\(^+\) and Cl\(^-\) are separated from each other.

To assess student understanding of Na\(^+\) and Cl\(^-\) being separated from each other when dissolving NaCl in water, students were asked to draw the arrangement of sodium chloride in water. Eighty-seven percent of students from the animation group correctly drew the arrangement compared to 96.88% of students in the non-animation group.

4.2.2.2 Mental Model Change

The third research question for Study 2 focused on students’ mental model change by examining before and after responses after the students viewed animations. The results and findings with the topics of states of water, and dissolving sodium chloride in water, are described separately below.

States of Water

Table 4.10

Percentage of students’ mental model change after applying animations in each key feature with the topic of states of water (N=32)

<table>
<thead>
<tr>
<th>Key Feature</th>
<th>1/</th>
<th>/X</th>
<th>XX</th>
<th>X/</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3 (1)</td>
<td>3 (1)</td>
<td>41 (13)</td>
<td>53 (17)</td>
</tr>
<tr>
<td>2</td>
<td>38 (12)</td>
<td>6 (2)</td>
<td>9 (3)</td>
<td>47 (15)</td>
</tr>
<tr>
<td>3</td>
<td>3 (1)</td>
<td>3 (1)</td>
<td>38 (12)</td>
<td>56 (18)</td>
</tr>
<tr>
<td>4</td>
<td>91 (29)</td>
<td>0</td>
<td>0</td>
<td>9 (3)</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>0</td>
<td>34 (11)</td>
<td>66 (21)</td>
</tr>
</tbody>
</table>

Note. Number in brackets is the number of students with correct answers

Key: 1/ = correct answer both pre-test and post-test
/X = correct answer pre-test and incorrect answer post-test
XX = incorrect answer both pre-test and post-test
X/ = incorrect answer pre-test and correct answer post-test

Mental model change is discussed in each key feature below.
**Key Feature 1:** Correct model of a molecule of water.

The correct model of a molecule of water is that: 1) a water molecule consists of two atoms of hydrogen and one atom of oxygen, and an atom of oxygen is larger than a hydrogen atom; and 2) a molecule of water is a bent shape.

Table 4.10 shows the percentage of students who exhibited a mental model change after applying animations in each key feature. Approximately 3% of students had correct answers in both the pre-test and post-test. About 3% of students who had correct answers in the pre-test had incorrect answers after viewing the animation. Forty-one percent of students had misconceptions before and after applying the animation (see Figure 4.9).

Although some students had misconceptions, other data suggested a broader improvement. Seventeen students (53% of the total class size) changed from incorrect to correct answers after viewing animation. Representative student drawings are shown below (see Figure 4.10):

*Figure 4.9.* Drawing of water molecules, misconceptions before and after viewing the animation.

*Figure 4.10.* Drawing of water molecules that were initially incorrect, but after viewing the animation displayed a better understanding.
**Key Feature 2**: Bent shape.

The shape of a water molecule is bent. Around 38% of students had correct answers before and after viewing the animation. Only 6% of students who correctly answered in pre-test had misconceptions after the animation (see Figure 4.11). Approximately 9% of students had incorrect answers both pre-test and post-test (Figure 4.12). After using the animation, 47% of students changed from incorrect to correct responses (see Figure 4.13).

![Figure 4.11](image1.png)

**Before** | **After**
--- | ---
*Figure 4.11.* Drawing of water molecules with bent shape that was correct before, but had misconceptions after viewing the animation

![Figure 4.12](image2.png)

**Before** | **After**
--- | ---
*Figure 4.12.* Drawing of water molecules with bent shape that had misconceptions before and after viewing the animation

![Figure 4.13](image3.png)

**Before** | **After**
--- | ---
*Figure 4.13.* Drawing of water molecules with bent shape that was incorrect before, but after viewing the animation demonstrated a better understanding
**Key Feature 3:** Different sized atoms of H and O.

A water molecule consists of two atoms of hydrogen and one atom of oxygen. An atom of oxygen is larger than a hydrogen atom. Approximately 3% of students had correct answers pre-test and post-test. Three percent of students had correct answers in the pre-test, but after viewing the animation had incorrect answers. About 38% of students had incorrect answers both in pre-test and post-test (see Figure 4.14). Approximately 56% of students had misconceptions before viewing the animation, but had correct answers after the viewing of animation (see Figure 4.15).

![Before](image1.png) ![After](image2.png)

*Figure 4.14.* Drawing of water molecules with different size atom of H and O that had misconceptions before and after viewing the animation

![Before](image3.png) ![After](image4.png)

*Figure 4.15.* Drawing of water molecules with different sized atoms of H and O that before the animation were incorrect, but after viewing the animation displayed a better understanding

**Key Feature 4:** Water molecules in liquid move.

Ninety-one percent of students had correct answers in both pre-test and post-test. Although many students understood that water molecules in liquid can move, they were confused between the movement of molecules of water in a liquid state
and the movement of water in a liquid state. Approximately 9% of students displayed improvement after using an animation.

**Key Feature 5**: Structure lattice in ice (arranged neatly, space).

Approximately 34% of students had incorrect answers before and after viewing the animation (see Figure 4.16). Although some students had misconceptions, data showed student improvement. Around 66% of students had correct answers after viewing the animation (see Figure 4.17).

*Figure 4.16. Drawing of structure lattice in ice that had misconceptions before and after viewing the animation*

*Figure 4.17. Drawing of structure lattice in ice that was incorrect before, but after viewing the animation displayed a better understanding*
Table 4.11

Percentage of students’ mental model change after applying animations in each key feature (N=32)

<table>
<thead>
<tr>
<th>Key Feature</th>
<th>//</th>
<th>/X</th>
<th>XX</th>
<th>X/</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>41 (13)</td>
<td>59 (19)</td>
</tr>
<tr>
<td>2</td>
<td>25 (8)</td>
<td>3 (1)</td>
<td>34 (11)</td>
<td>38 (12)</td>
</tr>
<tr>
<td>3</td>
<td>3 (1)</td>
<td>3 (1)</td>
<td>69 (22)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>6 (2)</td>
<td>0</td>
<td>69 (22)</td>
<td>25 (8)</td>
</tr>
<tr>
<td>5</td>
<td>56 (18)</td>
<td>3 (1)</td>
<td>10 (3)</td>
<td>31 (10)</td>
</tr>
</tbody>
</table>

Note: Number in brackets ( ) is the number of students with correct answers

Key:
//   = correct answer both pre and post-test
/X   = correct answer pre-test and incorrect answer post-test
XX   = incorrect answer both pre and post-test
X/   = incorrect answer pre-test and correct answer post-test

Mental model change is discussed in each key feature below.

**Key Feature 1: Size of Na\(^+\) smaller than Cl\(^-\).**

This key feature was used to assess student understanding of the structure of sodium chloride and, in particular, that Na\(^+\) is smaller than Cl\(^-\). Students were asked to draw the structure of sodium chloride. Forty-one percent of students had misconceptions before and after using the animation (see Figure 4.18). However, 59% who had a misconception in the pre-test gave a correct answer in the post-test after viewing the animation (see Figure 4.19).

![Before](image1.png) ![After](image2.png)

Figure 4.18. Drawing of the structure of sodium chloride that displayed misconceptions before and after viewing the animation.
**Key Feature 2:** Na\(^+\) and Cl\(^-\) are closely packed in solid sodium chloride.

The arrangement of ions in sodium chloride in a solid state is closely packed. Approximately 25% of students gave correct answers in both the pre-test and in the post-test. Approximately 3% of students who correctly answered in the pre-test answered incorrectly in post-test. Around 34% who had incorrect answers in the pre-test still had misconceptions in the post-test (see Figure 4.20). However, 38% of students who had incorrect answers in the pre-test gave correct answers after viewing the animation.

**Key Feature 3:** In melted sodium chloride, the ions are not so closely packed, and water molecules are not involved.

Students were asked to draw the arrangement of sodium ions and chloride ions when sodium chloride is melting. Sixty-nine percent of students had incorrect answers in both the pre-test and the post-test (see Figure 4.21). Only 25% of students had incorrect answers in the pre-test, but correct answers in the post-test.
(see Figure 4.22). Three percent had correct answers in the pre-test and in the post-test, or had correct answers in the pre-test but incorrect answers in the post-test.

**Figure 4.21.** Drawing of ions when NaCl is melting that displayed misconceptions before and after viewing the animation

**Figure 4.22.** Drawing of ions when NaCl is melting that was incorrect before, but after viewing the animation displayed a better understanding

**Key Feature 4:** Correct model of dissolving NaCl in water (Hydration of ion).

In dissolving sodium chloride in water, Na\(^+\) and Cl\(^-\) are separated from each other and are surrounded by water molecules. Sixty-nine percent of students had incorrect answers in both pre-test and post-test. Students therefore still have misconceptions about dissolving sodium chloride in water before and after viewing the animations (see Figure 4.23). Six percent of students had correct answers before and after using the animation. Twenty-five percent of students had incorrect answers in pre-test, but correct answers in post-test (see Figure 4.24).
Before

After

Figure 4.23. Drawing of the arrangement of dissolving sodium chloride in water that displayed misconceptions before and after viewing the animation

Before

After

Figure 4.24. Drawing of the arrangement of dissolving sodium chloride in water that was incorrect before but displayed a better understanding after viewing the animation

Key Feature 5: In sodium chloride solution, Na\(^+\) and Cl\(^-\) are separated from each other.

Fifty-six percent of students had correct answers in both pre-test and post-test. A few students, about 3%, had correct answers in the pre-test and incorrect answers after viewing the animation. Approximately 10% of students had incorrect answers in both the pre-test and in the post-test. However, 10 students (around 31%) had incorrect answers in the pre-test but correct answers after learning with the animation.

4.3 STUDY 3. THE EFFECTIVENESS OF USING ANIMATIONS IN THREE DIFFERENT SCHOOLS

The main aim of Study 3 was to implement and evaluate the VisChem animations for teaching and learning chemistry at the molecular level in three different settings including a university, a city school, and a rural school. Students in the 11th Grade, and a teacher in each school, participated. The chemistry topic used
was the redox reaction. Study 3 was not designed to analyse in deep detail why students in different schools might display differences in learning outcomes. One of the final recommendations in Chapter 6 is that the difference in results from the three schools might be a fruitful topic for further research.

Purposeful sampling was used as a strategy in data collection. The reason for conducting research in three different settings was because of the variations in terms of facilities and student background. The results gathered from this study might potentially offer insights for teaching and learning using animations in different settings.

The two research questions presented were: 1) Do animations help students understand the concept of the redox reaction at the molecular level? 2) How do students’ mental models change after applying animations? The results and findings in each school are presented below.

Students’ understanding, and their mental model changes, were ascertained by analysing a student drawing and explanations test. The test had three questions, and was checked by the same educators identified above for the Pilot Study and Study 2. The test was used to analyse students’ understanding as measured by test scores in total, and to examine mental model change with reference to before and after answers. The data analysis was the same as for the Pilot Study. The test for this study is shown in Appendix E.

4.3.1 School A (University School)

School A was a secondary school located at a university, and is considered to be a part of the university organisation. It covers teaching from Grade 7 to Grade 12. School A is well attended, with approximately 3,000 students and around 130 teachers. Class sizes typically varied between 35 to 45 students.

The teacher who participated in this research graduated with a master’s degree of chemistry and had eight years’ experience teaching chemistry. There were sufficient chemical substances for laboratory work, and six high quality laboratory
rooms in this school (see Figure 4.25). Students at School A were also provided the opportunity to attend occasional university lectures, and sometimes university professors would present guest lecturers to these students. Students at School A were allowed access to the university library and resources. Every teacher from this school has been competitively selected from the university undergraduate cohort who received at least an honours-level grade in chemistry. The students who study in this school have to pass a highly competitive entrance exam, with only about a 10% acceptance rate.

![Figure 4.25. A laboratory room from a university school](image)

### 4.3.1.1 Student Understanding

To answer whether animations helped students to understand the topic of redox reactions, pre-test and post-test scores from drawing tests were evaluated overall, and for each key feature. A paired samples t-test was used to compare pre-test and post-test student performance.

<table>
<thead>
<tr>
<th>Test</th>
<th>N</th>
<th>M</th>
<th>SD</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-test</td>
<td>14</td>
<td>0.21</td>
<td>0.43</td>
<td>-27.41</td>
<td>.00*</td>
</tr>
<tr>
<td>Post-test</td>
<td>14</td>
<td>3.86</td>
<td>0.36</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p<.05, one-tailed
A paired samples t-test was conducted to compare the mean scores of student understanding at the molecular level before and after using animation.

A statistically significant increase exists from the pre-test score before using animation ($M=0.21$, $SD=0.43$) to the post-test score after using animation ($M=3.86$, $SD=0.36$); $t (13) = -27.41$, $p=.00$.

Table 4.12 above describes overall test results obtained from 14 students. The progress from pre-test to post-test could also be analysed with reference to particular key features described and revealed in Table 4.13.

### Table 4.13
*Depicts the percentage change of students’ knowledge as measured by reference to correct responses to certain key features from pre-test to post-test*

<table>
<thead>
<tr>
<th>Items</th>
<th>Key Features</th>
<th>Percentage correct pre-test (N=14)</th>
<th>Percentage correct post-test (N=14)</th>
<th>Percentage change from pre-test to post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Metallic bonding, each positive ion is surrounded by an electron cloud</td>
<td>7</td>
<td>100</td>
<td>+93</td>
</tr>
<tr>
<td>2</td>
<td>Silver nitrate solution, Ag$^+$ and NO$_3^-$ ions are each surrounded by water molecules</td>
<td>14</td>
<td>100</td>
<td>+86</td>
</tr>
<tr>
<td>3</td>
<td>After placing the Cu(s) into the silver nitrate solution, each Cu atom loses two electrons to become a Cu$^{2+}$ ion surrounded by water molecules</td>
<td>0</td>
<td>100</td>
<td>+100</td>
</tr>
<tr>
<td>4</td>
<td>Ag$^+$ ions surrounded by water molecules gain one electron each from the copper metal lattice, to become Ag atoms</td>
<td>0</td>
<td>86</td>
<td>+86</td>
</tr>
</tbody>
</table>

**Key Feature 1:** Metallic bonding, each positive ion is surrounded by an electron cloud.

To assess students’ understanding about metallic bonding, students were asked to draw the arrangement of the particles in copper metal at the molecular level.
Only 7% of students could correctly answer in the pre-test. The low number of pre-test correct results means many students had misconceptions about metallic bonding before viewing the animation. In the pre-test drawings, some students did not draw the positive ion being surrounded by an electron cloud but drew positive ions and negative ions instead. However, after viewing the animation portraying metallic bonding in copper metal, all students responded correctly on this key feature. Students correctly portrayed metallic bonding as an electron cloud surrounding each positive ion.

**Key Feature 2:** Silver nitrate solution, Ag\(^+\) and NO\(_3^-\) ions are each surrounded by water molecules.

Students were asked to draw the arrangement of the particles in silver nitrate solution. Only 14% of students could draw a reasonable representation in the pre-test. Many students had misconceptions with this key feature, such as Ag\(^+\) and NO\(_3^-\) not being separated from each other. Some student drawings did not show Ag\(^+\) and NO\(_3^-\) ions as being surrounded by water molecules. After viewing the silver nitrate animation, 100% of students could draw the arrangement of the particles correctly.

**Key Feature 3:** After placing the Cu(s) into the silver nitrate solution, each Cu atom loses two electrons to become a Cu\(^{2+}\) ion surrounded by water molecules.

Students were asked to draw and explain the arrangement of the particles after the reaction that occurs when copper metal is added to silver nitrate solution. The question asked students to explain at the molecular level, so students had to observe the phenomenon at the observable level first, and then had to explain what happens at the molecular level.

The result from the pre-test showed that none of students could draw the arrangement of the particles after placing copper metal into silver nitrate solution. The fact that no students could draw the arrangement correctly indicated students’ difficulty in explaining chemical events at the abstract or molecular level. In the post-test, 100% of students drew the arrangement of the particles correctly.

**Key Feature 4:** Ag\(^+\) ions surrounded by water molecules gain one electron each from the copper metal lattice, to become Ag atoms.
Students were asked to draw and explain the arrangement of the particles of silver solution and silver after gaining an electron cloud from the copper metal. In the pre-test, none of the students could draw the arrangement correctly. However, after viewing the animation, 86% of students drew acceptable representations.

### 4.3.1.2 Mental Model Change

Data from students’ drawings, and explanations in pre-test and post-test questions, were analysed to determine mental model change after viewing the animations.

#### Table 4.14

*Percentages of students’ mental model change after applying animations in each key feature (N=14)*

<table>
<thead>
<tr>
<th>Key Feature</th>
<th>//</th>
<th>/X</th>
<th>XX</th>
<th>X/</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>93</td>
</tr>
<tr>
<td>2</td>
<td>14</td>
<td>0</td>
<td>0</td>
<td>86</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>14</td>
<td>86</td>
</tr>
</tbody>
</table>

Key:  
// = correct answer both pre-test and post-test  
/X = correct answer pre-test and incorrect answer post-test  
XX = incorrect answer both pre-test and post-test  
X/ = incorrect answer pre-test and correct answer post-test

Mental model change is discussed in each key feature below.

**Key Feature 1:** Metallic bonding, each positive ion is surrounded by an electron cloud.

Only 7% of students gave correct answers in both pre-test and post-test questions. After viewing the animation, 93% gave incorrect answers in the pre-test and gave correct answer for the post-test. The animation appears to have improved student understanding about the metallic bond, i.e., each positive ion is surrounded by an electron cloud.
Key Feature 2: In silver nitrate solution, $\text{Ag}^+$ and $\text{NO}_3^-$ ions are each surrounded by water molecules.

Only 14% of students had correct answers both in the pre-test and in the post-test. Eighty-six percent gave incorrect answers in the pre-test and gave correct answers for the post-test.

Key Feature 3: After placing the Cu(s) into the silver nitrate solution, each Cu atom loses two electrons to become a $\text{Cu}^{2+}$ ion surrounded by water molecules.

Interestingly, after viewing the animation, all students improved from an incorrect response in the pre-test to a correct response in the post-test.

Key Feature 4: $\text{Ag}^+$ ions surrounded by water molecules gain one electron each from the copper metal lattice, to become Ag atoms.

Fourteen percent of students had misconceptions before and after viewing the animation. However, 86% of students who initially answered incorrectly answered correctly after viewing the animation.

4.3.2 School B (City School)

School B was located in a city area. The school covers teaching from Grade 7 to Grade 12. The school is well attended, with approximately 3,000 students and around 120 teachers. The average class size is usually 40 to 50 students. The teacher who participated in this research graduated with a bachelor’s degree of chemistry, and had about fifteen years of experience teaching chemistry. Chemical substances were often limited or lacking. For example, there was no silver nitrate solution for this research. A laboratory room was available, but there was only one sink in front of the classroom (see Figure 4.26).
4.3.2.1 Student Understanding

Phase I, Study 3 was used to evaluate whether animations could help students from a city school understand redox reactions at the molecular level. The questions used, and the data analysis process, are the same as for School A (university school), and the results and findings are described below.

Table 4.15

Comparison of the mean before and after using the animations

<table>
<thead>
<tr>
<th>Test</th>
<th>N</th>
<th>M</th>
<th>SD</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-test</td>
<td>13</td>
<td>0.00</td>
<td>0.00</td>
<td>-8.12</td>
<td>.00*</td>
</tr>
<tr>
<td>Post-test</td>
<td>13</td>
<td>1.69</td>
<td>.75</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p<.05, one-tailed

A paired samples t-test was conducted to compare the score before and after viewing the animations. There was a statistically significant increase from the pre-test score before using animation (M=0.00, SD=0.00) to the post-test score after using animation (M=1.69, SD=0.75); t (12) = -8.12, p = .00.
Table 4.15 describes overall test results from the 13 students. The progress from pre-test to post-test can also be analysed with reference to particular key features described in Table 4.16.

Table 4.16

*The percentage change of students’ knowledge as measured by reference to correct responses to certain key features*

<table>
<thead>
<tr>
<th>Items</th>
<th>Key Features</th>
<th>Percentage of correct pre-test (N=13)</th>
<th>Percentage of correct post-test (N=13)</th>
<th>Percentage change from pre-test to post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Metallic bonding, each positive ion is surrounded by an electron cloud</td>
<td>0</td>
<td>92</td>
<td>+92</td>
</tr>
<tr>
<td>2</td>
<td>Silver nitrate solution, Ag⁺ and NO₃⁻ ions are each surrounded by water molecules</td>
<td>0</td>
<td>23</td>
<td>+23</td>
</tr>
<tr>
<td>3</td>
<td>After placing the Cu(s) into the silver nitrate solution, each Cu atom loses two electrons to become a Cu²⁺ ion surrounded by water molecules</td>
<td>0</td>
<td>54</td>
<td>+54</td>
</tr>
<tr>
<td>4</td>
<td>Ag⁺ ions surrounded by water molecules gain one electron each from the copper metal lattice, to become Ag atoms</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Key Feature 1:** Metallic bonding, each positive ion is surrounded by an electron cloud.

Students were asked to draw the arrangement of the particles from copper metal at the molecular level. In the pre-test, none of the students could draw the arrangement of the particles of copper metal. However, after viewing the animation, 92% of students responded correctly.

**Key Feature 2:** Silver nitrate solution, Ag⁺ and NO₃⁻ ions are each surrounded by water molecules.
Students were asked to draw the arrangement of particles in silver nitrate solution. None of the students could draw this question in the pre-test correctly. After viewing the silver nitrate solution animation, 23% of students could draw the arrangement of particles correctly.

**Key Feature 3:** After placing the Cu(s) into the silver nitrate solution, each Cu atom loses two electrons to become a Cu\(^{2+}\) ion surrounded by water molecules.

Students were asked to draw and explain the arrangement of particles in copper metal after the reaction between copper metal and silver nitrate solution. None of the students could draw the arrangement correctly pre-test. Fifty-four percent of students were able to respond correctly post-test.

**Key Feature 4:** Ag\(^+\) ions surrounded by water molecules gain one electron each from the copper metal lattice, to become Ag atoms.

Students were asked to draw and explain the arrangement of particles in silver nitrate solution and silver metal after gaining an electron from the copper lattice. In the pre-test, none of students could draw the arrangement of the particles of silver solution and the silver atom. After the animation, none of the students correctly responded.

### 4.3.2.2 Mental Model Change

The questions and data analysis process are the same as for School A. The details of the results and findings are described below.

Table 4.17

<table>
<thead>
<tr>
<th>Key Feature</th>
<th>//</th>
<th>/X</th>
<th>XX</th>
<th>X/</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>92</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>77</td>
<td>23</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>46</td>
<td>54</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>0</td>
</tr>
</tbody>
</table>
Key: // = correct answer both pre-test and post-test
/X = correct answer pre-test and incorrect answer post-test
XX = incorrect answer both pre-test and post-test
X/ = incorrect answer pre-test and correct answer post-test

Mental model change is discussed in each key feature below.

**Key Feature 1:** Metallic bonding, each positive ion is surrounded by an electron cloud.

Only 8% of students had incorrect answers both in the pre-test and in the post-test. Although some students had misconceptions before and after viewing the animation, 92% changed from incorrect responses in the pre-test to correct responses in the post-test.

**Key Feature 2:** Silver nitrate solution, Ag\(^+\) and NO\(_3\)^- ions are each surrounded by water molecules.

Seventy-seven percent of the students had incorrect answers both in the pre-test and in the post-test. Twenty-three percent of students displayed improvement after using animation.

**Key Features 3:** After placing the Cu(s) into the silver nitrate solution, each Cu atom loses two electrons to become a Cu\(^{2+}\) ion surrounded by water molecules.

Forty-six percent of students had incorrect answers both in the pre-test and in the post-test. Meanwhile, 54% of students changed from incorrect responses in the pre-test to correct responses in the post-test.

**Key Feature 4:** Ag\(^+\) ions surrounded by water molecules gain one electron from the copper metal lattice to become Ag atoms.

Before and after viewing animation, all of the students had incorrect answers.

### 4.3.3 School C (Rural School)

School C was located in a rural area. The school was about 25 kilometres away from the nearest city. It covers Grade 7 to Grade 12, and has approximately
450 students and 22 teachers. There are around 15 to 35 students in each class. The teacher who participated in this research graduated with a bachelor’s degree of general science, and had never taught chemistry before. Chemical substances are limited or lacking. A laboratory room, or a properly equipped classroom, is not guaranteed. For example, laboratory rooms sometimes have no sink (see Figure 4.27).

![A laboratory room from a rural school](image)

*Figure 4.27. A laboratory room from a rural school*

### 4.3.3.1 Student Understanding

This part of Study 3 was used to evaluate whether animations could help students from a rural school understand the redox reaction at the molecular level. The question and data analysis process was the same as for School A. The details of the results and findings are described below.

Table 4.18  
*Comparison of the mean before and after using animations*

<table>
<thead>
<tr>
<th>Test</th>
<th>N</th>
<th>M</th>
<th>SD</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-test</td>
<td>8</td>
<td>.00</td>
<td>.00</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Post-test</td>
<td>8</td>
<td>2.00</td>
<td>.00</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

SPSS cannot be used to compare pre-test and post-test for these reasons:

1. Small number of participants (8 students)
2. The scores from each student were the same
Table 4.19

*The percentage change of students’ knowledge as measured by reference to correct responses to certain key features from pre-test to post-test*

<table>
<thead>
<tr>
<th>Items</th>
<th>Key Features</th>
<th>Percentage of correct pre-test (N=8)</th>
<th>Percentage of correct post-test (N=8)</th>
<th>Percentage change from pre-test to post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Metallic bonding, each positive ion is surrounded by an electron cloud</td>
<td>0</td>
<td>100</td>
<td>+100</td>
</tr>
<tr>
<td>2</td>
<td>Silver nitrate solution, Ag⁺ and NO₃⁻ ions are each surrounded by water molecules</td>
<td>0</td>
<td>100</td>
<td>+100</td>
</tr>
<tr>
<td>3</td>
<td>After placing the Cu(s) into the silver nitrate solution, each Cu atom loses two electrons to become a Cu²⁺ ion surrounded by water molecules</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>Ag⁺ ions surrounded by water molecules gain one electron each from the copper metal lattice, to become Ag atoms</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Key Feature 1 and Key Feature 2.

None of the students could answer correctly in the pre-test. After viewing animations, all of the students correctly responded.

Key Feature 3 and Key Feature 4.

None of the students could answer correctly in the pre-test or in the post-test.

4.3.3.2 Mental Model Change

The question and data analysis process was the same as for School A. The details of the results and findings are described below.
Table 4.20
Percentages of students’ mental model change after applying animations in each key feature (N=8)

<table>
<thead>
<tr>
<th>Key Feature</th>
<th>//</th>
<th>/X</th>
<th>XX</th>
<th>X/</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>0</td>
</tr>
</tbody>
</table>

Key:  //  = correct answer both pre-test and post-test  
/ X  = correct answer pre-test and incorrect answer post-test  
XX  = incorrect answer both pre-test and post-test  
X/  = incorrect answer pre-test and correct answer post-test

Mental model change is discussed in each key feature below.

Key Feature 1 and Key Feature 2.
All students (eight students) displayed correct answers after using animations.

Key Feature 3 and Key Feature 4.
All students (eight students) had incorrect answers in the pre-test and in the post-test.

4.4 Conclusion

The main aim of this chapter was to evaluate the VisChem animations using different teachers located in different schools, with a number of classrooms, a number of settings, and varying molecular level topics. Key takeaways from Study 1 (Pilot Study), Study 2 (Animation and Non-Animation Groups), and Study 3 (University, City, Rural Schools) are summarised below.

4.4.1 Study 1 Findings (Pilot Study)

Two highlights of the Pilot Study were the apparent teacher misconceptions, and the results supporting the utility of animations.
The teacher in Study 1 displayed a variety of misconceptions, five of which were described above. Indeed, teacher misconceptions in chemistry have been identified in research as a significant issue (Kolomuc & Tekin, 2011; Lemma, 2013).

The Pilot Study results suggested a potential positive role for animations for molecular level chemistry instruction. Students generally understood (1) that hydrogen and oxygen from a molecule of water are different sized atoms, (2) that in melted sodium chloride, the sodium ions and chloride ions are not so closely packed, and water molecules are not involved, and (3) that for dissolved sodium chloride, the sodium ions and chloride ions are separated from each other, and each ion is surrounded by water molecules.

Although animations helped students understand, many students still retained certain misconceptions at the molecular level. For example, students incorrectly believed that in the melting of solid sodium chloride, water is used in the process. Students failed to draw water molecules surrounding the sodium ions and chloride ions in solution. These lingering misconceptions might be attributed to the process of teaching and learning where, for example, the teacher did not highlight the key features of animations, or did not provide multiple viewings of the animations. Other factors possibly influencing remaining misconceptions was that the audio speaker used for the animations was not clear enough, or loud enough, and students were not familiar with the method of drawing at the molecular level.

4.4.2 Study 2 Findings (Animation Group/Non-Animation Group)

Study 2 compared results between a class using animations and a class using other visualisation tools like pictures, or ball and stick models, but not animations. Similar teaching strategies were used in the animation and non-animation groups. Test results were mixed about the benefits of animations.

The teacher used the same basic teaching strategies for each classroom. Students engaged in the processes of observing, drawing, discussing and viewing. However, at the viewing step, the animation group used animations, whereas the other group used pictures, diagrams, and ball and stick models.
The results for the independent samples t-test showed that the animation group had a higher score on the topic of state of water than the non-animation group. By contrast, on the topic of dissolving sodium chloride in water, the animation group had a lower score than the non-animation group. These results suggested that animations could help students understand at the molecular level, but that static models such as pictures, diagrams and ball and stick models could also help students understand the concepts at the molecular level. For example, the static models can help students understand the bent shape of water molecules. By contrast, for the different sized atoms of hydrogen and oxygen (shown as the same size in the static model used in the classroom), or structure lattice in ice, the animations could help students understand more clearly than static models.

The results from the mental model analysis gathered from drawings showed that animations helped students understand at the molecular level for the topics of states of water and dissolving sodium chloride in water. For example, students understood the correct model of a molecule of water with a bent shape, understood the different sized atoms of hydrogen and oxygen, and understood that the structure in ice is arranged neatly and spaced.

Students displayed a variety of misconceptions after viewing animations. For example, students in the animation group incorrectly believed on the topic of melting sodium chloride that the sodium and chloride ions are paired together, and incorrectly believed for the topic of dissolved sodium chloride that the sodium and chloride ions are paired together. The misconceptions are similar to the Pilot Study. The students’ misconceptions may arise, in part, from the teaching strategies, or lack thereof. For example, the teacher did not explain the detail in each key feature to the students, and did not replay the animations even though the animations were in English and were perceived by the students as being too fast. Therefore, to help students understand each topic covered by animations, teacher guidance is required (Tasker & Dalton, 2006). The researcher recommends that the sound be turned off, and that the teacher provides a narration with frequent stoppages. Potential replays of the animations may be prudent.
4.4.3 Study 3 Findings (University/City/Rural Schools)

The results and findings from the three different schools after using animations are outlined below.

1. Results of understanding analysed from a paired sample t-test

Students from the university school and the city school showed a significant increase from in the pre-test (before using animation) to in the post-test (after using animation) p<.05(one-tailed). The mean of the post-test score showed university school: city school: rural school= 3.86:1.69:2. However, the paired sample t-test could not be used to compare the scores before and after using animations in the rural school because only eight students were in the class.

2. Results of understanding analysed from a percentage change from in the pre-test to in the post-test

University school students had better scores on all four key features. Students at the city school, by contrast, improved in only three key features (Key Features 1, 2 and 3). Students in the rural school improved on two key features (Key Feature 1 and 2).

3. Results of mental model change before and after applying animations.

When comparing the percentage change of students who changed from incorrect answers to correct answers after viewing animations, university students scored highest, followed by rural students with the next best improvement, followed by city students with the least improvement (91%>50%>42%). However, as noted above, the rural school had only eight students.

The results suggested some improvement in understanding and positive mental model change at all three schools. The university school students showed the most improvement. The reasons may be attributed to several factors. First, one could consider the quality of instruction. The teacher from the university school graduated with a master’s degree in chemistry and had eight years’ teaching experience. By contrast, the teacher from the city school graduated with a bachelor’s degree in chemistry, and had been teaching for 15 years, while the teacher from the rural school had the least amount of teaching experience—indeed, the rural instructor
had never taught chemistry before. Second, notable differences in the classroom facilities existed. The university school was modern, and well-equipped with laboratory supplies and equipment. By contrast, the city school was less equipped, and the rural school had basically no laboratory support. Finally, the background of the students could play a factor in the test results. The university students were selected from a highly competitive process. The city school had a slightly less competitive process, and some students could attend merely because of geographic proximity. Students at the rural school generally attend because it is close to their home, or because of financial or testing reasons they cannot attend a university or city school. The results from Study 3 suggested that multiple factors can influence the efficacy of VisChem animations to improve student understanding.

The results from Chapter 4 were used to develop the molecular level visualisation approach used in the next phase of this research, and the results and findings for the molecular level visualisation approach are described in Chapter 5.
CHAPTER 5
EVALUATION OF THE MOLECULAR LEVEL VISUALISATION APPROACH (PHASE II)

In the first phase of the study, it was concluded that VisChem animations can potentially play a meaningful and important role in achieving a deep understanding, but the animations need coupling with appropriate teaching methods. This chapter describes the evaluation of the molecular level visualisation approach.

The main aim of Phase II was to evaluate a learning design for molecular level visualisation when teaching and learning chemistry in secondary school classrooms. In Phase II, data were gathered from three classes in the same school in Thailand, identified as Class A, Class B, and Class C. For comparison purposes, different teaching approaches were used in each class. Each of the three classes was taught by the same chemistry teacher. The teacher had 15 years’ experience teaching chemistry. The students were all in the 11th Grade, and a total of 123 students participated. The topics in Phase II were sodium chloride in its solid state, sodium chloride in its liquid state, dissolving sodium chloride in water, silver nitrate solution, and ionic precipitation. In Class A, the teacher used a traditional approach (Chapter 1, Section 1.4) for the 42 students. Pictures and diagrams were used in this class consistent with the current and most common classroom practices in Thailand. In Class B, VisChem animations, pictures and diagrams were used with 41 students without the seven-step VisChem learning design. For Class C VisChem animations, pictures and diagrams were used with the seven step VisChem learning design, and involved 40 students. The approach used in Class C is referred to here as the molecular visualisation approach (see Chapter 2, Section 2.4).

The results, analysis and findings from the data collected from the three classes are described below.
5.1 Class A: The Traditional Approach

The traditional approach was used in Class A to determine if this approach could lead to a deep understanding of chemistry concepts, and to evaluate this method of classroom teaching. The following three research questions frame this part of the study:

1. How did the teacher teach and students learn chemistry using the traditional approach?
2. Does this approach help students achieve a deep understanding of particular concepts in chemistry?
3. How do students’ mental models change after using this approach?

The results and findings from Class A are described and discussed below. First, details about how the teaching was conducted are reported from classroom observations. Next, learning outcomes are reported and evaluated using specific test questions discussed below.

5.1.1 Teaching with the Traditional Approach

Observation data were obtained from a roughly two-hour classroom video recording. The teaching protocol used by the teacher in the class was analysed qualitatively using coding criteria (see Section 3.6.4), and categorised into three main steps: an experiment step, an explanation step, and a calculation step.

Experiment step

The 42 students were divided into groups, each containing about 5 to 6 students. The teacher gave each group some solid common salt (NaCl(s)) and test tubes, and began the class by prompting students with questions such as “What is the formula of salt?” and some students replied: “Sodium chloride” or “NaCl.” Students were asked to list the characteristics of salt and liquid water, and observe what happens after adding salt to water. Each group was then asked to describe their observations in front of the class. One student commented: “After we added salt into water, it became a solution and it is a pure substance.” This student appeared to have
the misconception that a solution was a pure substance. This is a common misconception because a clear solution resembles a homogeneous substance.

After the oral presentations were completed, the teacher summarised the lesson. The teacher said:

Solution is a substance where you can see only one state, or homogeneous substance, and it is colourless. Solution consists of two, or more than two, substances mixed together—one is called solvent and another one is called solute.

The teacher did not specifically point out the student’s misconception about a solution being a pure substance, even though the incorrect student comment might have offered a good teaching moment. It was apparent that the majority of the students were not paying attention in class, and were talking among themselves. The teacher’s voice was also rather soft.

Explanation step
After students completed the experiment step, the teacher distributed work sheets about what the term “solution” means. The teacher explained the meaning of solution as “a homogeneous substance where we can see only one state in that substance.” The teacher went on to explain that there are “three states of solution: solution can be in a solid state, a liquid state and a gas state (for example, the air that we breathe).”

Next, the teacher explained what a sodium chloride solution would look like at the molecular level by using a diagram from a Thai chemistry text book (see Figure 5.1).
With reference to the diagram in Figure 5.1, the teacher said that “during the dissolving process, the particles of solute will be inside the particles of solvent.” In fact, the particles of solute (sodium ions and chloride ions) are surrounded by water molecules (solvent). The teacher therefore had an apparent misconception about dissolving sodium chloride in water, and possibly did not understand the significance of hydration of the ions in enabling the process to occur.

The teacher’s explanation might create a misconception about dissolving sodium chloride in water. Sodium chloride in a solid state is a closely packed and ordered arrangement between sodium ions (Na\textsuperscript{+}) and the chloride ions (Cl\textsuperscript{-}). After adding water to salt, sodium ions and chloride ions are hydrated by water molecules resulting in sodium ions and chloride ions being separated from each other and surrounded by water molecules. However, this process was not explained accurately by the teacher. Furthermore, the teacher did not explain clearly that the hydrogen atom from a water molecule will face towards the chloride ion, and that the oxygen atom from a water molecule will face towards the sodium ion. Although the diagram of dissolved sodium chloride from the text book was clear, the diagram was static, and could not represent the movements of the particles. There is no clear indication that the process extends beyond the hydration of the two ions shown to all the ions in
the salt. Ultimately, the teacher was not able to explain this process clearly and accurately to the students.

The teacher then explained the chemical equation of sodium chloride solution. Below is the equation presented to the class by the teacher on a whiteboard in front of the room:

\[
\text{H}_2\text{O} \\
\text{NaCl}_{(s)} \rightarrow \text{Na}^+_{(aq)} + \text{Cl}^-_{(aq)}
\]

While presenting the general equation, the teacher provided no further elaboration on the equation. For example, the teacher did not explain the state of substance. Important questions such as “What does the (aq) mean?” or “Why does NaCl(s) change to be Na⁺(aq)?” or “What is a difference between Na and Na⁺?” were not presented to the students to encourage deep thinking.

During this part of the presentation to students, the teacher should encourage students to make connections between prior knowledge and new knowledge to form better conceptual understanding. To help students form a better conceptual understanding, the teacher should consider asking questions to explore student understanding in the class, and to help students connect to prior knowledge. To explain why dissolving happens, for example, the teacher should explain the competition between the attractive electrostatic forces keeping the ions together, and the combined ion-dipole attractions enabling water molecules to overcome these forces. The teacher did not verify that the students’ prior knowledge was accurate and accessible.

The next classroom activity involved ionic precipitation of AgCl. Students were not able to perform the experiment because there was no silver nitrate in the school. Therefore, the teacher tried to teach students at the symbolic level only. Below is the chemical equation for precipitation that the teacher presented to students, again on a whiteboard at the front of the classroom:

\[
\text{AgNO}_3 + \text{NaCl} \rightarrow \text{AgCl} + \text{Na}^+ + \text{NO}_3^-
\]
The teacher said “after we added silver nitrate solution to sodium chloride solution, and then mixed them together, the solution changed to be white precipitate.”

In the precipitation equation used by the teacher, the teacher did not write the state of substance. It is important to write the state of substance in the chemical equation to help students understand the chemical equation. For example, AgCl(s) means silver chloride in a solid state that does not dissolve significantly in water, and Na\(^+\)(aq) means the sodium ion is surrounded by water molecules. Moreover, the teacher used the chemical equation only, and did not provide a picture or diagram to explain what the equation meant at the molecular level.

In general, and understandably, the students appeared largely uninterested. The students did not actively participate by asking questions. On the other hand, the teacher did not use questions to engage the students.

**Calculation step**

The topic of concentration of solution was then introduced in this lesson. The 0.2M sodium chloride solution was used to explain how to calculate the concentration of each ion. The chemical equation for sodium chloride solution that the teacher used to explain to students is shown below:

\[
\text{NaCl} \rightarrow \text{Na}^+ + \text{Cl}^- \\
0.2\text{M} \quad 0.2\text{M} \quad 0.2\text{M}
\]

The teacher explained as follows:

Solid sodium chloride dissolves in water and the ions separate to form individual positive ions and negative ions, so the concentration of each ion is the same as the concentration of the solution. For example, the concentration of sodium chloride solution is 0.2 mol/L, and then the concentration of Na\(^+\) is 0.2 mol/L and Cl\(^-\) is 0.2 mol/L too.
The overall teaching presentation left several instructional opportunities unaddressed. The teacher again did not explain the state of the species in the equation. Left unexplained, the formula could leave uncertainty about an atom or ion of sodium (Na and Na⁺), and whether they are different from each other. The teacher did not explain the ratio of ions produced, so students could have a misconception if the ratio of ions in solution was not 1:1, for example, in a solution of magnesium chloride. Understanding the balanced chemical equation is a prerequisite to calculating the concentrations of ions in solution. The teacher did not explain the link between the symbolic level (equation) and the molecular level (arrangement of the particles in solution). The teacher could have drawn the arrangement of the particles in solution clearly, explained the concentration in each ion of the solution, and made connections between the molecular level and the symbolic level.

5.1.2 Learning Outcomes

The learning outcomes are discussed below in two parts: deep understanding and mental model change. Deep understanding was probed using the results from two transfer tests. The first transfer test was a multiple choice test with ten questions (see Appendix C), and the second transfer test was a calculation test with three main questions (see Appendix D). Mental model change was examined with reference to drawing and explanation results from five questions (see Appendix E), and was analysed according to fourteen key features.

The results and findings of deep understanding and mental model change are described below in turn.

5.1.2.1 Deep Understanding

The chemistry questions used in the transfer tests were different from the topics that were taught in the classroom. Tests focusing on topics that are related to, but different from, the classroom instruction can assist with determining the depth of student understanding. It is a common measure of depth of understanding if students can apply knowledge to new situations. Zirbel (2007, p. 20), for example, contrasts deep understanding where students can transfer knowledge to new areas, to learning
only the “superficial relationships between random facts” such as when students cram before a test. By using a different topic for testing, one can better assess students’ ability to transfer their knowledge to different, but related, chemistry topics.

For the ten-question multiple-choice test, a paired samples t-test was used to compare the results between pre-test and post-test scores in the same group (see Section 3.6.1). Data were cleaned before analysing to ensure the data are ready for analysis by eliminating inaccurate or incomplete records (Creswell, 2012). The data cleaning process revealed that all 42 students had submitted pre-test and post-test answer sheets, and all answer sheets were completed. The results from the multiple choice test are shown in Table 5.1 below.

Table 5.1

Comparison of the mean between pre-test and post-test scores using the traditional approach

<table>
<thead>
<tr>
<th>Test</th>
<th>N</th>
<th>M</th>
<th>SD</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-test</td>
<td>42</td>
<td>3.10</td>
<td>1.03</td>
<td>0.00</td>
<td>0.50</td>
</tr>
<tr>
<td>Post-test</td>
<td>42</td>
<td>3.10</td>
<td>1.37</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\( p \geq .05 \), one-tailed

Table 5.1 compares the test means between pre-test and post-test scores of the 42 students. The paired samples t-test was conducted to compare the scores of understanding at the molecular level. There was no significant increase from the pre-test score before using the traditional approach (\( M=3.10, SD=1.03 \)) to the post-test score after using the traditional approach (\( M=3.10, SD=1.37 \)); \( t(41) = 0.00, p= .50 \) (one-tailed). The calculation test data were analysed next using the conceptual evaluation scheme (see Section 3.6.2) and the results are shown in Table 5.2 below.

The calculation test described in Chapter 3 (see Section 3.5.1.2) was used because many students can resolve the problem with an algorithm, without necessarily understanding the underlying chemistry concepts. For example, Jansoon et al. (2009) stated that students can complete a problem involving concentrations of species in solution, but cannot explain the concept at the molecular level of
chemistry. Data analysis revealed that six students had not completed the post-test, and six students had not completed a pre-test. In total, 30 students submitted complete pre-tests and post-tests. All students had specific misconceptions prior to the instruction as shown in the pre-test results. The post-test results are described below and depicted in Table 5.2.

Table 5.2
The percentage of students’ knowledge as measured by the conceptual evaluation scheme with four groups in three questions in a class using a traditional approach (N=30)

<table>
<thead>
<tr>
<th>Questions</th>
<th>SU</th>
<th>PU</th>
<th>PUM</th>
<th>SM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>23 (7)</td>
<td>77 (23)</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>3 (1)</td>
<td>97 (29)</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>3 (1)</td>
<td>97 (29)</td>
</tr>
<tr>
<td>Total average</td>
<td>0%</td>
<td>0%</td>
<td>10%</td>
<td>90%</td>
</tr>
</tbody>
</table>

Note. Number in the brackets ( ) is the number of students in each group

SU = Sound Understanding
PU = Partial Understanding
PUM = Partial Understanding with Misconception
SM = Specific Misconception

Student responses are classified as follows:

**Sound Understanding (SU)**: The students submitted a correct answer for the calculation test. The students also drew the arrangement of the particles correctly, demonstrating knowledge of 80-100% of the key features.

**Partial Understanding (PU)**: The students submitted a correct answer for the calculation test. The students also drew the arrangement of the particles demonstrating that they understood 50-79% of the key features.

**Partial Understanding with Misconception (PUM)**: The students submitted a correct answer for the calculation test. The students also drew the arrangement of the particles but only demonstrated that they understood less than 50% of the key features. Alternatively, the students submitted an incorrect answer for the calculation.
test, but drew the arrangement of the particles demonstrating more than 50% of the key features.

**Specific Misconceptions (SM):** The students submitted an incorrect answer for the calculation test. The students also drew the arrangement of the particles demonstrating lack of understanding of less than 50% of the key features.

The results and findings in each question are discussed below.

**Question 1.** In a 0.5 mol/L KCl solution

(a) Calculate the concentration of K$^+$ and Cl$^-$ ions.

(b) Draw the particles in the KCl solution to include water molecules at the molecular level.

The students were asked to calculate the concentration of each ion in the 0.5 mol/L potassium chloride solution, and were also asked to draw the particles in the potassium chloride solution to include water molecules at the molecular level. The questions required an accurate calculation, and a visual drawing that showed their understanding at the molecular level.

Students were unable to calculate the concentration of each ion in potassium chloride solution, and they could not draw the particles in the solution appropriately. No students could be classified as having a sound understanding or a partial understanding. Seven students (23%) had a partial understanding with some misconceptions, and 23 students had specific misconceptions (77%). A majority of students could not give a correct answer for the concentration of each ion in the potassium chloride solution, and could not draw the arrangement of the particles in the potassium chloride solution correctly. Below is a correct symbolic representation of a 0.5M potassium chloride solution:

\[
\text{K}^+(\text{aq}) + \text{Cl}^-(\text{aq})
\]

\[
0.5\text{M} \quad 0.5\text{M}
\]

This representation shows that potassium chloride solution is an ionic solution containing hydrated potassium ions and chloride ions. Describing the
concentration of the solution as 0.5 mol/L KCl means that the concentrations of the hydrated potassium ions is 0.5 mol/L, and chloride ions 0.5 mol/L. Note that the potassium chloride solution tested here was similar to the sodium chloride solution presented in class, yet the students were still unable to use their knowledge and apply it to a very similar solution. Reasons for this apparent inability to transfer knowledge could come from many sources. Perhaps the teacher did not explain clearly enough, and there was little direct interaction between the teacher and students because the presentation was teacher dominated. The video recording also showed that some students did not appear to be paying attention in the classroom. Many students were talking together and did not appear to be focusing their attention on the teacher.

Student responses revealed some continuing misconceptions. Many students tried to resolve this problem by using a formula instead of writing the equation. For example, they use the following formula “mole = g/MW”. This incorrect formula showed that students were still confused between amount in moles, and concentration in mol/L. In other words they were unthinkingly using a formula they recalled without any understanding of the quantities involved.

Some students tried to write a chemical equation to resolve the problem, and the equations revealed further misconceptions (see Figure 5.2).

![Figure 5.2. Sample student equation for the potassium chloride solution](image)

Figure 5.2 indicates several misconceptions, such as 1) the Cl\(^{-}\) ion being composed of two non-existent ions—C\(^{+}\) and I—indicating a low prior knowledge about common ions and their charges; 2) equal sign (=) was used instead of an arrow (---->). The first misconception has been identified in the literature (Barke, 2012), and the second misconception is used in some older textbooks.
The drawings, meanwhile, were also illuminating. Analysis of the drawings revealed misconceptions about the particles in potassium chloride solution such as pairs of potassium ion and chloride ion with the ions in contact (see Figure 5.3). This most probably stems from the practice of using “KCl(aq)” to symbolically represent such a solution.

*Figure 5.3. Sample student drawing of the particles in potassium chloride solution revealing a common misconception*

Some students could draw the particles in potassium chloride solution as separated from each other, but many did not show the water molecules. Other students showed the oxygen-end of each water molecule facing the chloride ion, and the hydrogen-end of each water molecule facing the potassium ion (see Figure 5.4).

*Figure 5.4. Sample student drawing of the particles in potassium chloride solution revealing another common misconception*

**Question 2.** In a 0.5 mol/L MgCl\_2 solution
(a) Calculate the concentration of Mg\(^{2+}\) and Cl\(^-\) ions
(b) Draw the particles in the MgCl\_2 solution to include water molecules at the molecular level

Students were asked to calculate the concentration of each ion in 0.5 mol/L magnesium chloride solution, and were also asked to draw the particles in the
magnesium chloride solution to include water molecules at the molecular level. This item is similar to Question 1, but in this instance the question was used to probe whether students understood that the concentration ratio of each ion would not be 1:1.

No students could be classified as having a sound understanding, or even a partial understanding. Only one student held a partial understanding with misconception. Twenty-nine students (97%) had at least one specific misconception. Students could not give a correct answer for the concentration in each ion of 0.5 mol/L of magnesium chloride solution, and also could not draw the arrangement of the particles in solution correctly.

To resolve this problem effectively, students should start with writing the chemical equation for the dissolving reaction to produce the ionic solution. The correct equation is below:

\[
\text{MgCl}_2(\text{s}) \rightarrow \text{Mg}^{2+}(\text{aq}) + 2\text{Cl}^-(\text{aq})
\]

\[
0.5\text{M} \quad 0.5\text{M} \quad 2 \times 0.5\text{M}
\]

Before solving the problem, students need to understand the significance of the subscript “2” in MgCl₂ to see that two chloride ions are released for every magnesium ion.

Many students attempted to write the chemical equation for the production of a magnesium chloride solution. However, no students produced a balanced equation. An example of a student equation is shown in Figure 5.5:

\[
\text{Mg}_0(\text{s}) \rightarrow H_2O \rightarrow \text{K}^+ + 2\text{Cl}^-(aq)
\]

*Figure 5.5. One student’s writing of the chemical equation of magnesium chloride solution*
In the representative example above, a number of misconceptions are apparent. For example, 1) the reactant is magnesium chloride solution, but the student wrote only Mg; 2) the products from the equation must be Mg\(^{2+}\) (aq) and Cl\(^-\) (aq), but the student wrote K\(^+\) (aa) indicating confusion about magnesium and potassium; and 3) the student also wrote Cl (aa), thereby demonstrating a misconception about atom and ion between Cl and Cl\(^-\). Moreover, like in the equation above, many students still had a misconception about the state of substance. Students wrote (aa) for the aqueous state.

Some students did not write the equation to solve this problem. Regardless whether the students wrote the equation, or not, they could not give a correct answer, and still had misconceptions with the concentration of each ion in magnesium chloride solution.

The drawings revealed that more than 50% of the students drew the particles in solution in close contact, whereas other students drew the particles separated from each other without the water molecules. Some students drew the particles separated from each other and surrounded by water molecules, but still had misconceptions such as the oxygen-end of each water molecule facing the chloride ion.

**Question 3.** 50 mL 0.2 mol/L KCl is added to 100 mL 0.1 mol/L MgCl\(_2\)

(a) Calculate the total concentration of Cl\(^-\) ions after mixing the substances.

(b) Draw the correct ratio of particles in the mixed solutions of KCl and MgCl\(_2\) to include water molecules at the molecular level.

This question is more complex than Questions 1 and 2. To answer this question correctly, students would have to follow a several step process:

1) Write and balance the equations for the formation of each solution by dissolving the appropriate salt.

\[
\text{KCl (s) } \rightarrow \text{ K}^+ (aq) + \text{ Cl}^-(aq)
\]

\[
\text{MgCl}_2 (s) \rightarrow \text{ Mg}^{2+} (aq) + 2\text{ Cl}^- (aq)
\]

2) Calculate the amount of chloride ions in each solution by using the formula

\[n = c \cdot V\]

where \(n\) is the amount in moles, \(c\) is the concentration in mol/L and \(V\) is the solution volume in L.
In the potassium chloride solution
\[ n(\text{Cl}^-) = 0.2 \text{ mol/L} \times 50 \text{ mL} / 1000 \text{ mL/L} \]
\[ n(\text{Cl}^-) = 0.01 \text{ mol} \]

In the magnesium chloride solution
\[ n(\text{Cl}^-) = 0.2 \text{ mol/L} \times 100 \text{ mL} / 1000 \text{ mL/L} \]
\[ n(\text{Cl}^-) = 0.02 \text{ mol} \]

3) Calculate the total concentration of chloride ions in the solution by calculating the total amount of ions in the overall solution volume of 150 mL.
\[ n(\text{Cl}^-) = 0.02 \text{ mol (from MgCl}_2\text{ solution)} + 0.01 \text{ mol (from KCl solution)} \]
\[ n(\text{Cl}^-) = 0.03 \text{ mol} \]

Using the formula for concentration, \( c = \frac{n}{V} \),
\[ c(\text{Cl}^-) = 0.03 \text{ mol} / (150 \text{ mL} / 1000 \text{ mL/L}) \]
\[ c(\text{Cl}^-) = 0.2 \text{ mol/L} \]

The total concentration of chloride ion in the mixed solution is 0.2 mol/L.

In this question, no students had a sound understanding or a partial understanding. Only one student held a partial understanding with misconception. Twenty nine students (97%) had a specific misconception. No students could calculate the concentration of chloride ion after mixing the substance, and none could draw the particles of mixed solutions correctly.

Student difficulty with solving this problem could arise from different sources:

- students did not know where to start in a problem they had never seen before
- students could not write and balance the chemical equations necessary to calculate the overall concentration of chloride ions

Most importantly, we would claim that students who treated this problem as an algorithmic exercise, without being able to imagine what was happening when the ionic solutions were mixed at the molecular level, would not be able to do the solve the problem. This was demonstrated by the difficulties that students had linking the
molecular level and the symbolic level as demonstrated in both their calculations and their molecular level drawings. Below is an example calculation:

\[
\text{HCl} + \text{MgCl}_2 = \text{HCl} (aq) + \text{Mg} (aq) + \text{Mg} (aq)
\]

\[
2 \text{ mol} \ (0.2) \times 100 \ (0.1) = 1 \text{ mol} / L
\]

*Figure 5.6. Student incorrectly trying to calculate the concentration of chloride ion*

Figure 5.6 highlights some obvious problems. For example, the equation and the concentration calculation for each ion in each solution should be written separately. The drawings indicated their mistaken thinking, as shown by the figure below:

*Figure 5.7. Sample student drawing of the particles in a mixed potassium chloride and magnesium chloride solution*

Figure 5.7 shows that this student had a misconception about the arrangement of ions in the solution such as the particles in each solution not being separated from each other. Other students shared the same misconception.

The results and findings for mental model change are described below.

### 5.1.2.2 Mental Model Change

To examine mental model change, five specific test questions were devised. The questions were different from the deep understanding questions discussed above.
The five questions required students to draw, and explain, what was happening at the molecular level. Unlike the questions presented to probe deep understanding that tested the ability to transfer understanding to new but similar chemistry contexts covered in the classroom, the five questions described below were on the same chemistry contexts presented in the classroom. The post-test was administered two weeks after the class. Data from drawings and explanations in pre-test and post-test questions were analysed to find out how student mental models changed in five topics, and in particular “key features” in each topic (see Section 3.6.3).

Since seven students failed to complete pre-test submissions, only thirty five students completed both the pre-test and post-test. The results are described below.

Table 5.3

Percentages of students’ mental model change in each key feature before and after being taught with the traditional approach (N=35)

<table>
<thead>
<tr>
<th>Topic</th>
<th>Key Feature</th>
<th>//</th>
<th>/X</th>
<th>XX</th>
<th>X/</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium chloride in a solid state</td>
<td>1</td>
<td>3 (1)</td>
<td>11 (4)</td>
<td>40 (14)</td>
<td>46 (16)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>77 (27)</td>
<td>23 (8)</td>
</tr>
<tr>
<td>Sodium chloride in a liquid state</td>
<td>3</td>
<td>29 (10)</td>
<td>14 (5)</td>
<td>34 (12)</td>
<td>23 (8)</td>
</tr>
<tr>
<td>Sodium chloride solution</td>
<td>4</td>
<td>14 (5)</td>
<td>14 (5)</td>
<td>52 (18)</td>
<td>20 (7)</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>80 (28)</td>
<td>20 (7)</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>91 (32)</td>
<td>9 (3)</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>97 (34)</td>
<td>3 (1)</td>
</tr>
<tr>
<td>Silver nitrate solution</td>
<td>8</td>
<td>46 (16)</td>
<td>26 (9)</td>
<td>17 (6)</td>
<td>11 (4)</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>83 (29)</td>
<td>17 (6)</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>100 (35)</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>97 (34)</td>
<td>3 (1)</td>
</tr>
<tr>
<td>Precipitation</td>
<td>12</td>
<td>0</td>
<td>0</td>
<td>100 (35)</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>3 (1)</td>
<td>40 (14)</td>
<td>48 (17)</td>
<td>9 (3)</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>0</td>
<td>0</td>
<td>100 (35)</td>
<td>0</td>
</tr>
<tr>
<td>Total percentage average</td>
<td>7</td>
<td>8</td>
<td>73</td>
<td>12</td>
<td></td>
</tr>
</tbody>
</table>

*Note. The number in the brackets ( ) refers to the number of students who displayed a mental model change*
// = Correct answer both pre-test and post-test
/X = Correct answer pre-test and incorrect answer post-test
XX = Incorrect answer both pre-test and post-test
X/ = Incorrect answer pre-test and correct answer post-test

Table 5.3 depicts mental model change in one of four ways:

1) Before using the traditional approach, students have a correct mental model, and after applying the traditional approach the students maintained a correct mental model;

2) Before using the traditional approach, students had a correct mental model, but after applying the traditional approach students have an incorrect mental model (one or more);

3) Before using the traditional approach, students have an incorrect mental model, and after viewing the traditional approach students still have an incorrect mental model (one or more);

4) Before using the traditional approach, students have an incorrect mental model, and after applying the traditional approach students have a correct mental model.

Mental model change is further categorised according to five topics with 14 key features, discussed below.

**TOPIC 1: Sodium Chloride in its Solid State**

Students were asked to draw and explain the arrangement of sodium chloride in its solid state. For this topic, data were analysed for two key features. Key Features 1 and 2 are described below.

**Key Feature 1:** Na⁺ ions and Cl⁻ ions are closely packed in solid sodium chloride.

Table 5.3 shows the percentages of students’ mental model change after applying the traditional approach in each key feature. One student gave correct answers in both pre-test and post-test, and four students (11%) gave a correct answer in pre-test and an incorrect answer in post-test. Fourteen students (40%) gave incorrect answers in both pre-test and post-test. Students therefore still had a misconception in this key feature.
Figure 5.8 below is an example of a drawing from a student who demonstrated the misconception that the sodium and chloride ions are not closely packed.

![Pre-test and Post-test drawings of ions in solid sodium chloride](image1)

*Figure 5.8.* A sample student pre-test and post-test drawing of the arrangement of ions in solid sodium chloride.

Less than half of the students drew the arrangement of sodium ions and chloride ions paired together in solid sodium chloride. The drawings suggested that these students had misconceptions with the arrangement of ions in solid sodium chloride in both the pre-test and post-test. However, some students drew the sodium ions and chloride ions as separated from each other in solid sodium chloride.

Although many students had misconceptions, other data showed improvement in student understanding. Sixteen students (46%) displayed correct answers after the traditional approach (see Figure 5.9).

![Pre-test and Post-test drawings of ions in solid sodium chloride](image2)

*Figure 5.9.* A sample pre-test and post-test drawing of the arrangement of ions in solid sodium chloride.
In Figure 5.9, students initially drew the sodium and chloride ions as separated from each other. However, after learning through the traditional approach, students could draw the arrangement of ions in the solid correctly.

**Key Feature 2**: Na\(^{+}\) and Cl\(^{-}\) ions are closely packed and ordered in solid sodium chloride.

No students gave correct answers in the pre-test. Twenty-seven students (77%) had incorrect answers in both pre-test and post-test, and eight students (8%) went from incorrect to correct answers. It seemed that a large number of students still had misconceptions before and after learning with the traditional approach.

**TOPIC 2: Sodium Chloride in Liquid State**

Students were asked to draw and explain the arrangement of the particles in melted sodium chloride. Student demonstration of Key Feature 3 was evaluated to indicate whether the student had a correct mental model of melted sodium chloride after applying the traditional approach.

**Key Feature 3**: In melted sodium chloride, the ions are not so closely packed, and water molecules are not involved.

Ten students (29%) gave correct answers in both pre-test and post-test, thus indicating some potential prior knowledge about this key feature. However, five students (14%) gave a correct answer in pre-test, and an incorrect answer in post-test. Interestingly, twelve students (34%) had incorrect answers in both pre-test and post-test, showing a persistent misconception about the arrangement of ions in melted sodium chloride. Many students thought that water is involved in melting sodium chloride, revealing the common misunderstanding of the terms “melting” and “dissolving”. Some students thought that sodium ions and chloride ions are paired together in melted sodium chloride. Eight students (23%) gave incorrect answers in pre-test, and a correct answer in post-test. Below is an example of a student’s drawing with misconceptions both pre-test and post-test:
Figure 5.10. Sample drawing of the arrangement of ions in melted sodium chloride

In the pre-test, this particular student drew the sodium ions and chloride ions paired together, surrounded by water molecules. Although the student drew sodium ions and chloride ions separated from each other in the post-test, the misconception persisted that water molecules were involved in melted sodium chloride.

**TOPIC 3: Sodium Chloride in Solution**

Four key features are used to assess student mental model change after applying the traditional approach.

**Key Feature 4**: $\text{Na}^+$ and $\text{Cl}^-$ ions are separated from each other in dissolved sodium chloride.

Five students (14%) had correct answers in both the pre-test and post-test. Five students (14%) gave a correct answer in the pre-test and an incorrect answer in the post-test. Eighteen students (52%) gave incorrect answers in both the pre-test and post-test questions. Only seven students (20%) changed from incorrect to correct responses.

**Key Feature 5**: $\text{Na}^+$ and $\text{Cl}^-$ ions are separated from each other, and each ion is surrounded by water molecules, in sodium chloride solution.

No students gave correct answers in the pre-test. Twenty-eight students (80%) had incorrect answers in both the pre-test and post-test (see Figure 5.11), and seven students (20%) gave correct answers after the traditional approach.
The pre-test drawing (refer to Figure 5.11) shows that one student drew the sodium ions and chloride ions as separated from each other and, in some parts of the drawing, this student drew sodium ions and chloride ions as inside water molecules. Before learning using the traditional approach, this student demonstrated an obvious misconception about sodium chloride solution. After learning using the traditional approach, this student still retained this misconception. The post-test drawing shows only water molecules in sodium chloride solution. This student wrote “after dissolving sodium chloride in water, we can see it is colourless, meaning it changed to be water.” Similarly, other students showed misconceptions about sodium chloride solution such as “during the time of dissolving sodium chloride, the size of the particle in salt will become smaller and smaller, and then we cannot see the salt because it changed to become dissolved sodium chloride.” The students were still confused about the molecular level and observable level, and had obvious difficulties imagining what was happening at the molecular level.

**Key Feature 6:** The oxygen atoms in water molecules face towards the Na\(^+\) ions in sodium chloride solution.

No students gave correct answers in the pre-test. Thirty-two students (91%) had incorrect answers in both pre-test and post-test. Only three students (9%) gave correct answers after learning through the traditional approach.

**Key Feature 7:** The hydrogen atoms in water molecules face towards the Cl\(^-\) ions in sodium chloride solution.
No students gave correct answers in the pre-test. Thirty-four students (97%) had incorrect answers in both pre-test and post-test. Only one student (3%) changed from incorrect to correct answers.

**TOPIC 4: Silver Nitrate Solution**

This topic is similar to the sodium chloride solution, and students were asked to draw and explain the arrangement of particles in silver nitrate solution. For silver nitrate solution, Key Features 8 to 11 are discussed below.

**Key Feature 8:** $\text{Ag}^+$ and $\text{NO}_3^-$ ions are separated from each other in silver nitrate solution.

Sixteen students (46%) had correct answers in both the pre-test and post-test. Many students appear to have already known about the arrangement of silver nitrate solution. One could speculate that the question is similar to the sodium chloride solution question that students had been previously exposed to in the classroom. Nine students (26%) gave a correct answer in the pre-test, and an incorrect answer in the post-test, and six students (17%) gave incorrect answers in both the pre-test and in the post-test. Only four students (11%) changed from incorrect to correct responses.

**Key Feature 9:** $\text{Ag}^+$ and $\text{NO}_3^-$ ions are separated from each other, and each ion is surrounded by water molecules, in silver nitrate solution.

No students gave correct answers in the pre-test. Twenty-nine students (83%) had incorrect answers in both the pre-test and post-test (see Figure 5.12).

![Pre-test](image1)

![Post-test](image2)

*Figure 5.12. Drawing of the arrangement of ions in silver nitrate solution*
The pre-test drawing by the student presented in Figure 5.12 shows that silver ions are inside nitrate ions. Other students had similar representations. This misconception might be language based. “Ni” in Thai language means inside, therefore, silver nitrate solution perhaps is interpreted by students as meaning that the silver ion is inside the nitrate ion. After being exposed to teaching through the traditional approach, students drew the particles as separated from each other, but water molecules were still missing in the solution. Only six students (17%) changed from incorrect to correct responses.

**Key Feature 10:** The oxygen atoms in water molecules face towards the Ag\(^+\) ions in silver nitrate solution.

All thirty-five students (100%) had incorrect answers in both the pre-test and in the post-test (see Figure 5.13).

![Pre-test](image1) ![Post-test](image2)

*Figure 5.13. Student drawing of the arrangement of ions in silver nitrate solution*

The pre-test drawing above shows only silver ions and nitrate ions as separated without water molecules, and the post-test drawing shows that this particular student had a better understanding. In the post-test drawing, each ion was shown as being separated from each other and surrounded by water molecules. However, like other students, this student still possesses a misconception about how the hydrogen and oxygen from water molecules face towards the silver ion and nitrate ion.
**Key Feature 11:** The hydrogen atoms in water molecules face towards the $\text{NO}_3^-$ ions in silver nitrate solution.

No students gave correct answers in the pre-test. Thirty-four students (97%) had incorrect answers both pre-test and post-test, and only one student changed from incorrect to correct answers.

**TOPIC 5: Precipitation**

Students were asked to draw and explain the arrangement of the particles after mixing a solution of sodium chloride and silver nitrate solution. Student drawings were marked with reference to Key Features 12 to 14 which are described below.

**Key Feature 12:** Silver ions and chloride ions are closely packed in silver chloride precipitate.

All students gave incorrect answers in both the pre-test and in the post-test (see Figure 5.14).

*Figure 5.14. Drawing the arrangement of ions in silver chloride precipitate by a particular student*

The pre-test and post-test drawings showed that misconceptions persisted. In the pre-test, students commonly drew each ion of sodium chloride solution and silver nitrate solution as being separated from each other. In the post-test drawings, such as the sample above in Figure 5.14, all of the students displayed a misconception about the arrangement of silver chloride precipitation. Students drew all ions as closely packed. In fact, after the two solutions are mixed together, the silver ions and chloride ions are closely packed, but sodium ions and nitrate ions are separated from each other and surrounded by water molecules.
**Key Feature 13:** Sodium and nitrate ions remain separated from each other after silver chloride precipitation.

One student had correct answers both in the pre-test and in the post-test. Fourteen students (40%) gave correct answers in the pre-test, but in the post-test provided incorrect answers. Seventeen students (48%) gave incorrect answers both in the pre-test and in the post-test, and only three students (9%) changed the answer from incorrect in the pre-test to a correct answer in the post-test.

**Key Feature 14:** Sodium and nitrate ions remain separated from each other as hydrated ions after silver chloride precipitation.

All thirty-five students (100%) gave incorrect answers in both the pre-test and in the post-test.

In summary, for 12 of the 14 key features, students had misconceptions before and after learning chemistry with the traditional approach. Only Key Feature 1 showed the number of students who gave an incorrect answer in the pre-test and a correct answer in the post-test ($X/\text{ in the legend}$) was higher than for the other groups, and in Key Feature 8 the number of students who gave correct answers both in the pre-test and in the post-test ($//\text{ in the legend}$) was higher than for the other groups.

### 5.2 Class B: Using VisChem Animations with the Traditional Approach

Class B used a traditional approach, but the teacher also incorporated VisChem animations. The essential difference between Class A and Class B is that animations were used to depict molecular level events, in addition to the pictures and diagrams used in traditional instruction. The aim of this study was to examine whether incorporating animations as additional visualisations, without any specific learning design, could help students to achieve a deeper understanding than without using animations. The research questions, the tests and data analysis used for Class B were the same as those for Class A (Traditional Approach).

The results and findings from Class B using animations with the traditional approach are described and discussed below.
5.2.1 Teaching with the Traditional Approach using Animations

Observation data were obtained from roughly two hours of video recording. The same teacher who taught Class A taught Class B, and used the same basic teaching techniques. All 41 students were divided into smaller groups of 5 to 6 students. The teacher guided students with experiments, followed by explanation and a calculation step.

Students in this group also covered the same topics as for Class A—states of salt (solid, liquid and solution) and precipitation. The teacher was better able to link the observable level, molecular level and symbolic level in her teaching because animations were incorporated. Students in Class B could see the observable level of the phenomenon of substances that Class A did not—Class A did not have silver nitrate solution, and no experiment was carried out (and animations were not a part of the Class A traditional approach method).

Class B observed by video the reactions and substances of melted sodium chloride and precipitation between silver nitrate solution and sodium chloride solution. The animations were shown to students only once during the explanation step (similar to Class A that was presented with various static visualisations at the explanation stage). The teacher drew pictures and diagrams on a blackboard to supplement the animations. The teacher did not ask students to draw their mental model of the substances and reaction at the molecular level before or after viewing the animations. The classroom method was still teacher-dominated, and the students were passive learners.

5.2.2 Learning Outcomes

The learning outcomes are discussed below in two parts: deep understanding and mental model change. The tests and data analysis were the same as for Class A, and will be described in context below.
5.2.2.1 Deep Understanding

Two transfer tests were used to examine whether student deep understanding had improved with the teaching approach that used animations: (1) a multiple choice test, and (2) a calculations test. Both data analyses are described below.

For the multiple choice tests, all 41 students submitted complete pre-test and post-test answer sheets.

Table 5.4

<table>
<thead>
<tr>
<th>Test</th>
<th>N</th>
<th>M</th>
<th>SD</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-test</td>
<td>41</td>
<td>3.61</td>
<td>1.46</td>
<td>-0.25</td>
<td>.39</td>
</tr>
<tr>
<td>Post-test</td>
<td>41</td>
<td>3.68</td>
<td>1.49</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$p > .05$, one-tailed

Table 5.4 compares the test means of the 41 students before and after learning with animations in a class taught by traditional means. The paired samples t-test was conducted to compare the scores of deep understanding at the molecular level of chemistry. There was no significant increase from the pre-test score before using animations in the traditional approach ($M=3.61, SD=1.46$) to the post-test score after using animations in the traditional approach ($M=3.68, SD=1.49$); $t(40)= -0.25, p= .39$ (one-tailed).

Three students had incomplete pre-tests, and three students had incomplete post-tests. These incomplete scripts were not included in the analysis. Therefore, 35 students submitted complete before and after tests. All students had specific misconceptions prior to teaching as shown in the pre-test results. The post-test results are described below and depicted in Table 5.5.
Table 5.5

The percentage of students’ knowledge as measured by the conceptual evaluation scheme with four groups in three questions in a class using a traditional approach with animations (N=35)

<table>
<thead>
<tr>
<th>Questions</th>
<th>SU</th>
<th>PU</th>
<th>PUM</th>
<th>SM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>43 (15)</td>
<td>0</td>
<td>31 (11)</td>
<td>26 (9)</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>54 (19)</td>
<td>46 (16)</td>
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<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>20 (7)</td>
<td>80 (28)</td>
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<tr>
<td>Total average</td>
<td>14%</td>
<td>0%</td>
<td>35%</td>
<td>51%</td>
</tr>
</tbody>
</table>

*Note.* Number in the bracket ( ) is the number of students in each group

SU = Sound Understanding
PU = Partial Understanding
PUM = Partial Understanding with Misconceptions
SM = Specific Misconceptions

The questions below were the same as those used in Class A. The results and finding are described and discussed below.

**Question 1.** In a 0.5 mol/L KCl Solution.

(a) Calculate the concentration of K\(^+\) and Cl\(^-\) ions.

(b) Draw the particles in the KCl solution to include water molecules at the molecular level.

The results indicated that fifteen students (43%) had a sound understanding of the meaning of 0.5 mol/L potassium chloride solution; that is, students could calculate the concentration of each ion of potassium chloride solution, and also could draw the particles in the solution correctly. Eleven students (31%) had a partial understanding, with at least one misconception. Nine students (26%) had a specific misconception.

The method that students used to answer this question was to write the chemical’s ionic equation first, and then to write the concentration (mol/L) in each ion (see Figure 5.15).
Although the answer of the concentration of each ion was correct in the example above, some students did not write the chemical equation correctly. In Figure 5.16 below, the student did not write the states of the chemical species. This student also incorrectly wrote the potassium ion as K instead of K\(^+\), and incorrectly wrote chloride ion as Cl instead of Cl\(^-\). It seemed this student was confused about the difference between an ion and an atom of potassium and chloride.

More than 50% of the students tried to use the formula to resolve this problem instead of using the chemical equation (Figure 5.17)

Students were asked to calculate the concentrations (mol/L) of the particles in the solution. Many tried to solve this problem without understanding the concept of concentration of solution. The formula they used could not help them calculate the
concentration of the ions in the potassium chloride solution because the formula in Figure 5.17 was for the amount of chloride ions. It seemed that the students were confused between amount (mol) and concentration (mol/L).

Several students drew the particles in the solution correctly and, in so doing, displayed an apparent understanding of several points: 1. Potassium and chloride ions are separated from each other; 2. Each ion is surrounded by water molecules; 3. The oxygen atoms in the water molecules face towards the K$^+$ ions; and 4. The hydrogen atoms in the water molecules face towards the Cl$^-$ ions. Although understanding several of these points, many students still confused whether the oxygen or hydrogen atoms in the water molecules should face each ion, as shown in Figure 5.18.

![Figure 5.18. Drawing of the particles in the potassium chloride solution (better understanding) by a particular student](image)

The above figure demonstrates an overall sound understanding about the arrangement of particles in the potassium chloride solution.

Other drawings showed that many students still had misconceptions. For example, in Figure 5.19, one student drew the ions in potassium chloride solution separated from each other, but each ion was connected to a water molecule. This student, and other students, still had misconceptions about the arrangement of the ions and molecules in solution after viewing the animations in the transmissive traditional approach.

![Figure 5.19. Drawing the particles in the potassium chloride solution incorrectly](image)
Question 2. In a 0.4 mol/L MgCl$_2$ Solution

(a) Calculate the concentration of Mg$^{2+}$ and Cl$^-$ ions

(b) Draw the particles in the MgCl$_2$ solution to include water molecules at the molecular level

No students demonstrated a sound understanding or a partial understanding in this question. Nineteen students (54%) held a partial understanding with at least one misconception. Sixteen students (46%) had a specific misconception.

No students could calculate the concentration of each ion of magnesium chloride solution correctly. Students tried to answer this question by using two main methods. First, some students tried to write the ionic equation, but did not balance it. Failing to balance the ionic equation was the main reason that students could not give a correct answer of the concentration of each ion in the solution. Second, other students tried to use the formula for amount in the form they were taught—“mole=CV/1000”—before writing the ionic equation. Students who used this formula to solve the given problem seemed confused about the difference between amount (mol) and concentration (mol/L).

In terms of drawing, many students could draw the arrangement of the particles in the solution correctly, depicting the particles as separated from each other and surrounded by water molecules. However, students still had misconceptions about the arrangement of the particles in solution such as the oxygen-end of each water molecule facing towards the chloride ion. Another common misconception was that the particles in solution are not separated from each other.

Question 3. 50 mL 0.2 mol/L KCl is added to 100 mL 0.1 mol/L MgCl$_2$

(a) Calculate for the total concentration of Cl$^-$ ions after mixing the substances.

(b) Draw the correct ratio of particles in the mixed solutions of KCl and MgCl$_2$ to include water molecules at the molecular level.
No students had a sound understanding or a partial understanding. Seven students (20%) held a partial understanding with misconception. Twenty-eight students (80%) had a specific misconception.

The results and finding of the mental model change are described and discussed below.

### 5.2.2.2 Mental Model Change

Data from the pre-test and post-test drawings were used to analyse how students’ mental models changed. The tests and data analysis were the same as used for Class A. All 41 students completed answers in the pre-test and in the post-test. The results are summarised below in Table 5.6.

**Table 5.6**

Students’ mental model change measured as a percentage before and after applying animations with the traditional approach in each key feature (N=41)

<table>
<thead>
<tr>
<th>Topic</th>
<th>Key Feature</th>
<th>/</th>
<th>X</th>
<th>XX</th>
<th>X/</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium chloride in a solid state</td>
<td>1</td>
<td>24 (10)</td>
<td>10 (4)</td>
<td>22 (9)</td>
<td>44 (18)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>7 (3)</td>
<td>15 (6)</td>
<td>54 (22)</td>
<td>24 (10)</td>
</tr>
<tr>
<td>Melted sodium chloride</td>
<td>3</td>
<td>5 (2)</td>
<td>7 (3)</td>
<td>54 (22)</td>
<td>34 (14)</td>
</tr>
<tr>
<td>Sodium chloride solution</td>
<td>4</td>
<td>27 (11)</td>
<td>22 (9)</td>
<td>7 (3)</td>
<td>44 (18)</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>39 (16)</td>
<td>61 (25)</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>61 (25)</td>
<td>39 (16)</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>93 (38)</td>
<td>7 (3)</td>
</tr>
<tr>
<td>Silver nitrate solution</td>
<td>8</td>
<td>34 (14)</td>
<td>27 (11)</td>
<td>24 (10)</td>
<td>15 (6)</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>64 (26)</td>
<td>36 (15)</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>83 (34)</td>
<td>17 (7)</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>93 (38)</td>
<td>7 (3)</td>
</tr>
<tr>
<td>Precipitation</td>
<td>12</td>
<td>0</td>
<td>0</td>
<td>98 (40)</td>
<td>2 (1)</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>19 (8)</td>
<td>15 (6)</td>
<td>44 (18)</td>
<td>22 (9)</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>0</td>
<td>0</td>
<td>73 (30)</td>
<td>27 (11)</td>
</tr>
<tr>
<td>Total percentage average</td>
<td>8</td>
<td>7</td>
<td>58</td>
<td>27</td>
<td></td>
</tr>
</tbody>
</table>

*Note.* Number in the bracket ( ) refers to the number of students who displayed a mental model change.
// = Correct answer both pre and post-test
/X = Correct answer pre-test and incorrect answer post-test
XX = Incorrect answer both pre-test and post-test
X/ = Incorrect answer pre-test and correct answer post-test

The data analysis used was the same as for Class A. Mental model change for Class B is summarised according to five topics and 14 key features, described below.

**TOPIC 1: Sodium Chloride in its Solid State**

Students were asked to draw and explain the arrangement of sodium chloride in its solid state. For this topic, data was analysed for Key Feature 1 and Key Feature 2, described below.

**Key Feature 1**: Na\(^+\) ions and Cl\(^-\) ions are closely packed in solid sodium chloride.

Table 5.6 shows the percentage of students’ mental model change after learning with animations in the traditional approach in each key feature. Ten students (24%) gave correct answers in the pre-test and in the post-test, and four students (10%) who correctly answered in the pre-test answered incorrectly in the post-test. Nine students (22%) gave incorrect answers in both the pre-test and post-test.

Although some students had misconceptions, other data suggested a broader improvement. Eighteen students (44%) displayed correct answers after learning with an animation using the traditional approach. For example, some students initially drew the arrangement of sodium ions and chloride ions as not closely packed. However, after learning with an animation, students could draw the arrangement of ions in the solid state correctly (see Figure 5.20).

![Pre-test Post-test](image)

*Figure 5.20. A sample student pre-test and post-test drawing of the arrangement of ions in solid sodium chloride*
**Key Feature 2:** Na\(^+\) and Cl\(^-\) ions are closely packed and ordered in solid sodium chloride.

Three students (7%) gave correct answers in the pre-test and in the post-test, and six students (15%) who correctly answered in the pre-test answered incorrectly in the post-test. Twenty-two students (54%) had incorrect answers both in the pre-test and in the post-test.

Results showed that students’ mental model changed after learning with animations: ten students (24%) went from incorrect to correct answers.

**TOPIC 2: Sodium Chloride in Liquid State**

Students were asked to draw and explain the arrangement of the particles in melted sodium chloride. Key Feature 3 and Key Feature 4 help evaluate whether students had a correct mental model of melted sodium chloride after learning with an animation in the traditional approach.

**Key Feature 3:** In melted sodium chloride, the ions are not so closely packed, and water molecules are not involved.

Two students (5%) gave correct answers in the pre-test and in the post-test, and three students (7%) who correctly answered in the pre-test provided incorrect answers in the post-test. Twenty-two students (54%) gave incorrect answers both in the pre-test and in the post-test (see Figure 5.21). Fourteen students (34%) went from incorrect to correct answers.

*Figure 5.21. Sample drawing of the arrangement of ions in melted sodium chloride*

Figure 5.21 indicates that this particular student retained a misconception about the arrangement of the sodium ions and chloride ions in melted sodium chloride.
chloride after learning with the animation. In the pre-test, the student drew the sodium ion and chloride ion as paired together, surrounded by water molecules. The drawing resembled drawings from Class A using the traditional approach without animations. Although this student did not draw the water molecules in the post-test, the student still drew sodium ions and chloride ions as paired together.

**TOPIC 3: Sodium Chloride in Solution**

For this topic, four key features were used to assess whether students have a correct mental model after applying animations with the traditional approach.

**Key Feature 4**: Na\(^+\) and Cl\(^-\) ions are separated from each other in dissolved sodium chloride.

Eleven students (27%) had correct answers both in the pre-test and in the post-test. Nine students (22%) gave a correct answer in the pre-test, and an incorrect answer in the post-test. Only three students (7%) gave incorrect answers both in the pre-test and in the post-test questions. Eighteen students (44%) changed from incorrect to correct responses (see Figure 5.22).

![Pre-test](image1.png)  ![Post-test](image2.png)

*Figure 5.22. Drawing by one particular student on the arrangement of ions in dissolved sodium chloride*

Figure 5.22 shows the arrangement of the ions in dissolved sodium chloride before and after being presented an animation as depicted by that student, and other students. In the pre-test, students drew sodium ions and chloride ions as paired together, and some ions were separated from each other by water molecules. Although in the post-test students drew sodium ions and chloride ions as separated from each other, and surrounded by water molecules, the students still possessed a
misconception about the direction the oxygen atoms in water molecules face relative to the chloride ions.

**Key Feature 5**: Na\(^+\) and Cl\(^-\) ions are separated from each other, and each ion is surrounded by water molecules, in sodium chloride solution.

No students gave correct answers in the pre-test. Sixteen students (39%) gave incorrect answers both in the pre-test and in the post-test, and twenty-five students (61%) went from incorrect answers in the pre-test to correct answers in the post-test.

**Key Feature 6**: The oxygen atoms in water molecules face towards the Na\(^+\) ions in sodium chloride solution.

No students gave correct answers in the pre-test. Twenty-five students (61%) gave incorrect answers both in the pre-test and post-test. Although some students had misconceptions, sixteen students (39%) displayed correct answers in the post-test.

**Key Feature 7**: The hydrogen atoms in water molecules face towards the Cl\(^-\) ions in sodium chloride solution.

No students gave correct answers in the pre-test. Thirty-eight students (93%) had incorrect answers both in the pre-test and in the post-test. Only three students (7%) changed from incorrect to correct responses.

**TOPIC 4: Silver Nitrate Solution**

Students were asked to draw and explain the arrangement of silver nitrate solution. For silver nitrate solution, Key Features 8 to 11 are described below.

**Key Feature 8**: Ag\(^+\) and NO\(_3^-\) ions are separated from each other in silver nitrate solution.

Fourteen students (34%) had correct answers both in the pre-test and post-test. Eleven students (27%) gave correct answers pre-test but changed to be incorrect answers in the post-test. Ten students (24%) gave incorrect answers both in the pre-test and in the post-test. However, six students (15%) changed from incorrect to correct responses.
**Key Feature 9:** Ag$^+$ and NO$_3^-$ ions are separated from each other, and each ion is surrounded by water molecules, in silver nitrate solution.

No students gave correct answers in the pre-test. Twenty-six students (64%) had incorrect answers both in the pre-test and in the post-test (see Figure 5.23), and only fifteen students (36%) changed from incorrect to correct responses.

![Pre-test](image1)

![Post-test](image2)

*Figure 5.23. Sample student drawing of the ions in silver nitrate solution*

The pre-test drawing showed the silver ions and nitrate ions as bonded together without water molecules. After viewing an animation, students incorrectly drew the particles of silver ions, nitrated ions and water molecules as bonded together.

**Key Feature 10:** The oxygen atoms in water molecules face towards the Ag$^+$ ions in silver nitrate solution

No students gave correct answers in the pre-test. Thirty-four students (83%) had incorrect answers both in the pre-test and in the post-test, and seven students (17%) went from incorrect answers in the pre-test to correct answers in the post-test.

**Key Feature 11:** The hydrogen atoms in water molecules face towards the NO$_3^-$ ions in silver nitrate solution

No students gave correct answers in the pre-test. Thirty-eight students (93%) had incorrect answers both in the pre-test and post-test, and three students (7%) changed from incorrect to correct answers.

**TOPIC 5: Precipitation**

Students were asked to draw and explain the arrangement of the particles after mixing a solution consisting of sodium chloride and silver nitrate solution.
Student drawings were marked with reference to Key Features 12 through 14, described below.

**Key Feature 12:** Silver ions and chloride ions are closely packed in silver chloride precipitate.

No students correctly answered pre-test. Forty students (98%) gave incorrect answers both in the pre-test and post-test. Only one student changed from incorrect to correct responses.

**Key Feature 13:** Sodium and nitrate ions remain separated from each other after silver chloride precipitation.

Eight students (18%) had correct answers both in the pre-test and in the post-test. Six students (15%) gave correct answers in the pre-test, but in the post-test provided incorrect answers. Eighteen students (44%) gave incorrect answers in the pre-test and in the post-test, and nine students (22%) changed the answer from incorrect in the pre-test to correct answers in the post-test.

**Key Feature 14:** Sodium and nitrate ions remain separated from each other as hydrated ions after silver chloride precipitation.

No students gave correct answers in the pre-test. Thirty students (73%) had incorrect answers both in the pre-test and in the post-test (see Figure 5.24), and eleven students (27%) had incorrect answers in the pre-test and correct responses in the post-test.

*Figure 5.24. Sample student drawing of the arrangement of particles after mixing silver nitrate and sodium chloride solutions*
Figure 5.24 suggests that misconceptions remained even after viewing the animation. Pre-test, this student drew ions of sodium chloride solution and ions of silver nitrate solution as bonded together. The post-test drawing showed that this student still had a misconception about the arrangement of silver chloride precipitation. The student drew sodium ions and chloride ions as bonded with the water molecule, and silver ions and nitrate ions as bonded with the water molecules.

5.3 Class C: Application of the Molecular Level Visualisation Approach

In this thesis the molecular level visualisation approach refers to the use of VisChem animations, pictures, and diagrams, presented within the seven steps of the VisChem learning design. This approach was used in Class C to determine if it was effective for facilitating deeper understanding. Students’ mental models were examined, as were the teaching steps used. The following three research questions frame this inquiry:

1. How did the teacher teach and students learn chemistry using the molecular level visualisation approach to promote a deep understanding?
2. Does the molecular level visualisation approach help students achieve a deep understanding at the molecular level?
3. How do students’ mental models change after using the molecular level visualisation approach?

The results and findings from Class C are described and discussed below in two parts. The first part details the seven steps of the molecular level visualisation approach, and provides analysis of those steps from the video of classroom teaching. The second part analyses the learning outcomes.

5.3.1 Teaching with the Molecular Level Visualisation Approach

Research question number one examines how the teacher taught and students learned when using the molecular level visualisation approach. Observation data were collected from analysis of video recordings in the classroom. Two to four hours of the chemistry instruction were recorded on video, covering the following
topics: sodium chloride in its solid state, melted sodium chloride, sodium chloride solution, silver nitrate solution, and the precipitation of silver chloride.

The seven steps of the VisChem learning design (see Section 2.4) used in the molecular level visualisation process are described below with reference to specific in-class activities. The chemistry teacher was the same as the one who taught Class A and Class B. The teacher was trained and guided by the researcher about how to teach students with the molecular level visualisation approach prior to the lessons. Below is an example of teaching using the molecular level visualisation approach in seven steps with the topic of sodium chloride in a solid state.

**Topic: Sodium Chloride in a Solid State**

*Step 1. Observing a phenomenon*

The 40 students in Class C were divided into groups of between 5-6 students. The teacher prepared salt and test tubes for each group. During this step, students observed the characteristics of salt in the solid state in a test tube, and discussed what they saw with each other (see Figure 5.25). Students were asked to think about the arrangement of ions in the solid salt at the molecular level, supported with teacher-guided questions. Below is a sample of the teacher-guided questions:

*Teacher:* Salt is a white crystal. Have you ever seen particles of sodium chloride in a solid state before? If you can see the particles, what do you think about the arrangement of the particles of sodium chloride in a solid state?

During this step, students could also observe salt in a multimedia video provided as a part of the VisChem package.
Step 2. Describing and drawing a molecular-level representation to explain the phenomenon

After students observed the solid salt, they drew the arrangement of the particles in the solid using either a pen or pencil on paper provided by the teacher. The teacher drew representations of the sodium ion and chloride ion on the whiteboard for students to use as a key so that everyone used the same convention, and these representations assisted with comparison of student drawings. The teacher continued to engage students by asking questions to help them think at the molecular level. Below is an example of a question that the teacher used:

Teacher: Can you imagine the arrangement of salt at the molecular level? If you zoom down to the salt at the molecular level, what can you see? Draw the particle from your imagination on the paper that I provided. I will draw the building blocks of the sodium ion and chloride ion for you on the whiteboard.

Step 3. Discussing representations with peers

After students drew the arrangement of salt at the molecular level, students then used their drawings of salt to discuss with peers in their own group. Below is the teacher’s direction to the students:
**Teacher:** After you have completed your drawing, you can discuss your drawing with your friends. I mean, you can share your drawings with each other, and talk together about the pictures that you drew. However, please do not copy from each other. Just use your own ideas. You have to explain your drawings, too.

The teacher asked students in each group to orally present the arrangement of salt at the molecular level. Groups of students took turns to stand in front of the classroom and to present by drawing the arrangement of salt at the molecular level on the whiteboard (see Figure 5.26).

*Figure 5.26. Students discussing and presenting about the particles of salt in a solid state*

**Step 4. Viewing animations to resolve conflict**

During Step four, the teacher presented an animation depicting solid sodium chloride to students through an overhead projector (see Figure 5.27). During the presentation of the animation, the teacher provided general guidance at various times, such as:

*Teacher:* A chloride ion is green, and a sodium ion is grey. The particles will be arranged in an alternating and ordered pattern. You can see that the particles can vibrate in a fixed position. Normally we cannot see this with our eyes.
The teacher drew pictures and diagrams on the arrangement of sodium chloride in a solid state on the whiteboard after completion of the animation to provide further explanation.

![Sodium Chloride - Chemical Formula](image)

**Figure 5.27.** Still frame of sodium chloride in a solid state from *VisChem* animation

**Step 5. Reflecting on any differences between new and prior conceptions**

After viewing the animation, and seeing pictures and diagrams of the particles of sodium chloride in a solid state, the class proceeded to reflect on their current understanding compared to their original understanding. The teacher asked students to draw the particles of sodium chloride in a solid state to compare with the previous drawings they had made during Step 2 (see Figure 5.28).

<table>
<thead>
<tr>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Na⁺ and Cl⁻" /></td>
<td><img src="image" alt="Na⁺ and Cl⁻" /></td>
</tr>
<tr>
<td>น้ำตาล ปิโตร เทส</td>
<td>น้ำตาล ปิโตร เทส</td>
</tr>
</tbody>
</table>

“Na⁺ is closed to Cl⁻”  "The particles will be closed together and vibrating”

**Figure 5.28.** Student drawings before and after viewing the animation of salt in a solid state
Step 6. Expressing the ideas using symbols and scientific terms

In this step, the teacher explained the different levels of chemistry. The teacher talked about the observable level where students could see salt in a solid state, and then compared those observations to the particles of salt at the molecular level as depicted in the animation and follow-on pictures and diagrams. Finally, the teacher discussed the formula of salt at the symbolic level. See the diagram below that depicts the various levels canvassed by the teacher:

![Diagram linking between three levels of thinking](image)

Figure 5.29. Diagram linking between three levels of thinking

Step 7. Transferring the ideas to new situations

The teacher asked students various questions to help them think at a deeper level about what they had observed, what they had drawn, and what they had previously discussed. For example, the teacher asked questions such as the following:

Teacher: If the temperature is increased for salt in a solid state, what happens to the particles of salt?

Teacher: If we added water into the salt, where is the salt, and what do you think the arrangement of salt is after dissolving in water?

During this final step, the teacher also taught students about how to calculate the concentration of each ion in solution. The teacher used sodium chloride solution to explain how to calculate the concentration of each ion. This was the same teacher
who had taught Class A and Class B, and this teacher did not explain the balancing of chemical equations.

5.3.2 Learning Outcomes

The learning outcomes are discussed below in two parts: deep understanding and mental model change. Deep understanding was probed using the data from two transfer tests. The first transfer test was a multiple choice test with ten questions, and the second transfer test was a calculation test with three main questions. Mental model change was examined with reference to drawing and explanation results from five questions, and as analysed according to fourteen key features. The tests were the same as used for Class A.

The results and finding from deep understanding and mental model change are described and discussed below.

5.3.2.1 Deep Understanding

Two transfer tests were used to find out whether students’ deep understanding improved: (1) a multiple choice test, and (2) a calculations test.

For the multiple choice test, ten questions were presented. A paired samples t-test was used to compare the results between pre-test and post-test scores within the same group.

Two students had only submitted a post-test answer sheet, and two students had only submitted a pre-test answer sheet. These incomplete scripts were not included in the analysis. Therefore, a total of 36 complete answer sheets were available for analysis.
Table 5.7

Comparison of the mean between pre-test and post-test scores when using the molecular level visualisation approach.

<table>
<thead>
<tr>
<th>Test</th>
<th>N</th>
<th>M</th>
<th>SD</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-test</td>
<td>36</td>
<td>3.00</td>
<td>1.33</td>
<td>-13.26</td>
<td>.00</td>
</tr>
<tr>
<td>Post-test</td>
<td>36</td>
<td>6.81</td>
<td>1.41</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[ p < .05, \text{one-tailed} \]

Table 5.7 compares the means between pre-test and post-test scores of the 36 students before and after applying the molecular level visualisation approach. The paired samples t-test was conducted to compare the score of understanding at the molecular level before and after applying the molecular level visualisation approach. There was a significant increase from the pre-test score prior to teaching \((M=3.00, SD=1.33)\) to the post-test score after being exposed to the molecular level visualisation approach \((M=6.81, SD=1.41)\); \(t(35)=-13.26, p=.00\) (one-tailed).

For the calculation tests, a conceptual evaluation scheme was used to analyse the data. The conceptual evaluation scheme was the same as used for Class A and Class B (see Section 3.6.2). Four students had not completed a pre-test submission, and three students had not provided a post-test submission. Therefore, 33 students submitted complete pre-test and post-test scripts. All students had specific misconceptions prior to instruction as shown in the pre-test results. The post-test results are described below and depicted in Table 5.8.

Table 5.8

The percentage of students’ knowledge as measured by a conceptual evaluation scheme with four groups in three questions when using the molecular level visualisation approach \((N=33)\)

<table>
<thead>
<tr>
<th>Questions</th>
<th>SU</th>
<th>PU</th>
<th>PUM</th>
<th>SM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>49 (16)</td>
<td>33 (11)</td>
<td>9 (3)</td>
<td>9 (3)</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>94 (31)</td>
<td>6 (2)</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>91 (30)</td>
<td>9 (3)</td>
</tr>
<tr>
<td>Total average</td>
<td>16%</td>
<td>11%</td>
<td>65%</td>
<td>8%</td>
</tr>
</tbody>
</table>

Note. Number in the brackets ( ) is the number of students in each group
SU     = Sound Understanding
PU     = Partial Understanding
PUM = Partial Understanding with Misconception
SM    = Specific Misconception

**Question 1.** In a 0.5 mol/L LiCl Solution

(a) Calculate the concentration of Li\(^+\) and Cl\(^-\) ions.

(b) Draw the particles in the LiCl solution to include water molecules at the molecular level.

The students were asked to calculate the concentration of each ion of the 0.5 mol/L lithium chloride solution, and were also asked to draw the particles in the lithium chloride solution to include water molecules at the molecular level. The calculation and drawing assesses not only whether students can provide a correct calculation, but whether the students can draw and understand at the molecular level. Sixteen students (49%) held a sound understanding about the concentration of a single atom solution. These 16 students could calculate the concentration of each ion of lithium chloride solution, and also could draw the particles in the solution correctly. The way that students solved this problem was to write the ionic representation first, and then to write the concentration (mol/L) in each ion. Following is an example:

\[
\begin{align*}
\text{H}_2\text{O} \\
\text{LiCl(s)} &\rightarrow \text{Li}^+ \text{ (aq)} + \text{Cl}^- \text{ (aq)} \\
0.5 \text{ mol/L} &\quad 0.5 \text{ mol/L} \quad 0.5 \text{ mol/L}
\end{align*}
\]

Although the ionic representation was written correctly, some students still missed the state of substance in the equation. For example, students wrote LiCl \(\rightarrow\) Li\(^+\) + Cl\(^-\) without indicating the state of substance.

Students who could draw the particles in the solution correctly displayed an understanding of the following points: 1. Lithium and chloride particles are separated from each other; 2. The particles are surrounded by water molecules; 3. The oxygen atoms in the water molecules face towards the Li\(^+\); 4. The hydrogen atoms in the
water molecules face towards the Cl\(^-\). The following Figure 5.30 represents a correct understanding:

![Figure 5.30](image)

*Figure 5.30. Drawing the particles in the lithium chloride solution correctly*

Many students being able to draw the particles in the solution correctly could relate to the very recent, prior classwork during this research. The students had already studied the arrangement of ions and molecules in sodium chloride solution using the molecular level visualisation approach. Sodium chloride solution has a ratio of 1:1 for the sodium ion and chloride ion, and the ratio of the lithium ion and chloride ion in lithium solution is the same, 1:1. That similarity could have affected the large number of correct drawings.

Eleven students (33%) had a partial understanding with misconception, and specific misconceptions were held by only three students (9%). Some students could not calculate the concentration of the particles in lithium chloride solution, and had tried to use the formula for amount instead (i.e., Mole=CV/1000).

Students who used the formula for amount did not understand the difference between concentration and amount. The unit mol/L is used for measuring the concentration of solution. The formula for amount would not help students solve a calculation for concentration.

The drawing of the particles in solution showed other misconceptions, such as oxygen atoms in the water molecules facing towards the Cl\(^-\) ions, and hydrogen atoms in the water molecules facing towards the Li\(^+\) ions (see Figure 5.31).
Figure 5.31. Sample student drawing of the particles in the lithium chloride solution

Nevertheless, while some students had misconceptions, a majority of students could draw the arrangement of the particles in solution correctly (i.e., the particles are separated from each other, and the particle are surrounded by water molecules).

Student misconceptions could be linked, in part, to the animations. As applied to the water molecule, for instance, it seems that students were unclear about which parts of the animation represented oxygen, and which parts represented hydrogen. Therefore, the teacher should present the building blocks of the substance used in the classroom. For example, the teacher could explain that the building block of the water molecule is two atoms of hydrogen having a white colour, and one atom of oxygen having a red colour, where the oxygen atom is larger than the hydrogen atom (see Figure 5.32)

Figure 5.32. A representation of a water molecule in a VisChem animation
Question 2. In a 0.5 mol/L CaCl₂ Solution

(a) Calculate the concentration of Ca²⁺ and Cl⁻ ions
(b) Draw the particles in the CaCl₂ solution to include water molecules at the molecular level

Students were asked to calculate the concentration in each ion in 0.5 mol/L calcium chloride solution, and were also asked to draw the particles in the calcium chloride solution to include water molecules. This item is similar to Question 1, but in this instance was used to assess whether students understood about the concentration of each ion if the ratio of each ion is not 1:1.

No students had a sound understanding or a partial understanding. Thirty one students (94%) held a partial understanding with misconception. Two students (6%) had a specific misconception. No students could calculate the concentration of each ion of calcium chloride solution correctly.

Examination of the calculation test results revealed that the students had not balanced the ionic equation, and the students also ignored the states of chemical species. For example, some students made the following equation:
CaCl₂ ------ > Ca²⁺ + Cl⁻.

Some students displayed another misconception when they wrote the following equation: Ca ----- > Cl⁻. Students retained misconceptions about the chemical equation and charge of the ion. Ca should be written as Ca²⁺. This incorrect calculation showed that certain students had misconceptions about the differences between atom, molecule and ion.

Another misconception involved the formula that students used to solve this problem. Similar to the way students approached Question 1, students again attempted to use the formula for amount to resolve this question, i.e., mole = CV/1000. However, to solve Question 2 correctly, students had to be able to write and balance the ionic equation. For example,
CaCl₂(s) ------ > Ca²⁺(aq) + 2Cl⁻(aq)
0.5 mol/L 0.5 mol/L (0.5x2) mol/L
Collectively, these misconceptions seem to demonstrate that students had a low prior knowledge about the chemical equation. By Year 11 in school, the students should have learned how to write a chemical equation. Writing the chemical equation is a Year 10 topic in the Thai chemistry curriculum. The results here demonstrate that the teacher should spend extra effort in helping students to make connections between new knowledge and the students’ prior knowledge.

The 31 students who could draw the particles in the solution correctly understood the following: 1. Calcium and chloride particles are separated from each other; 2. Calcium and chloride particles are surrounded by water molecules; 3. The oxygen atoms in the water molecules face towards the Ca\(^{2+}\); 4. The hydrogen atoms in the water molecules face towards the Cl\(^{-}\). However, all of the students incorrectly drew one chloride ion instead of two chloride ions (see Figure 5.33).

![Sample incorrect drawing of the particles in the calcium chloride solution](image)

*Figure 5.33. Sample incorrect drawing of the particles in the calcium chloride solution*

**Question 3.** 50 mL 0.2 mol/L LiCl is added to 100 mL 0.1 mol/L CaCl\(_2\)

(a) Calculate for the total concentration of Cl\(^{-}\) ions after mixing the substances.

(b) Draw the correct ratio of particles in the mixed solutions of LiCl and CaCl\(_2\) to include water molecules at the molecular level.

Students were presented with a complex question about how to calculate the concentration of chloride ion in the mixed solution, and were asked to draw the particles of mixed solution between 50 mL, 0.2 mol/L lithium chloride solution with 100 mL 0.1 mol/L calcium chloride solution. In this question, no students had a sound understanding or a partial understanding. Thirty students (91%) held a partial
understanding with misconception. Three students (9%) had a specific misconception.

No students could calculate the concentration of chloride ion in the mixed solution correctly. The process that students used to solve this problem was using the formula of mole = CV/1000 or \( n = c \cdot V \) to calculate the mole of chloride ion in each solution, and after that they used the same formula to calculate the concentration of chloride ion in mixed solution. The process of calculation was suitable, but the misconception stemmed from the calculation for mole of chloride ions in calcium chloride solution. Students incorrectly used one calcium ion per chloride ion 1:1. In fact, the mole of Ca\(^{2+}\): Cl\(^{-}\) is 1:2. Because of this misconception, students could not calculate a correct answer. No students could draw the particles with the correct ratio of Li\(^{+}\): Cl\(^{-}\):Ca\(^{2+}\) as 1:3:1.

Although all students had a misconception about the ratio of ions, many students could draw ions in the mixed solution correctly where ions are separated from each other and surrounded by water molecules.

The primary point is that teachers can, and should, offer guidance in this process by way of in-class assistance, handouts, or otherwise helping students to connect old knowledge with new knowledge. Students need to connect the new instruction about concentration of substances with their Year 10 chemistry notes about chemical equations.

5.3.2.2 Mental Model Change

Mental model change was examined with five questions requiring students to draw and explain what was happening at the molecular level. Unlike the questions used to probe deep understanding that tested the ability to transfer understanding to new but similar chemistry contexts covered in the classroom, the five questions described below were on the same chemistry contexts presented in the classroom (i.e., sodium chloride in solid state, melted sodium chloride, sodium chloride solution, silver nitrate solution and precipitation). Data from student drawings and explanations in the pre-test and post-test, and interviews with 28 students, were used...
to analyse how student mental models changed. Responses were organised with five topics and according to fourteen key features within those five topics. The test and data analysis was the same as used for Class A and Class B.

Two students provided incomplete pre-test submissions, and three students had not completed post-test submissions. Therefore, complete data were obtained from 35 students. The results are described below in Table 5.9.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Key Feature</th>
<th>//</th>
<th>/X</th>
<th>XX</th>
<th>X/</th>
</tr>
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<td>Sodium chloride in a solid state</td>
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<td>0</td>
<td>23</td>
<td>51</td>
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<tr>
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<td>2</td>
<td>0</td>
<td>0</td>
<td>46</td>
<td>54</td>
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<tr>
<td>Melted sodium chloride</td>
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<td>0</td>
<td>3</td>
<td>74</td>
</tr>
<tr>
<td>Sodium chloride solution</td>
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<td>28</td>
<td>9</td>
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<td></td>
<td>5</td>
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<td>0</td>
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<td>77</td>
</tr>
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<td></td>
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<td>7</td>
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<td>0</td>
<td>49</td>
<td>51</td>
</tr>
<tr>
<td>Silver nitrate solution</td>
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<td>17</td>
<td>11</td>
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<td>40</td>
<td>60</td>
</tr>
<tr>
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<td>3</td>
<td>57</td>
<td>40</td>
</tr>
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<td>14</td>
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<td>0</td>
<td>34</td>
<td>66</td>
</tr>
<tr>
<td>Total (average percentage)</td>
<td>8</td>
<td>3</td>
<td>32</td>
<td>57</td>
<td></td>
</tr>
</tbody>
</table>

Note. The number in the brackets ( ) refers to the number of students who displayed a mental model change

// = Correct answer both pre-test and post-test
/X = Correct answer pre-test and incorrect answer post-test
XX = Incorrect answer both pre-test and post-test
X/ = Incorrect answer pre-test and a correct answer post-test
TOPIC 1: Sodium Chloride in its Solid State

Students were asked to draw and explain the arrangement of sodium chloride in its solid state. For this topic, data were analysed for two key features. Key Features 1 and 2 are described below.

**Key Feature 1:** Na⁺ ions and Cl⁻ ions are closely packed in solid sodium chloride.

Nine students (26%) gave correct answer both in the pre-test and in the post-test. No students gave correct answers in the pre-test but incorrect answers in the post-test. Eight students (23%) had incorrect answers both in the pre-test and post-test (see Figure 5.34).

*Figure 5.34.* Pre-test and post-test drawing by one student of the arrangement of ions in solid sodium chloride

Figure 5.34 indicates that the student had a misconception about the arrangement of ions in solid sodium chloride. That misconception was shared by other students. This student thought that sodium chloride was only sodium and chloride ions connected together. This common misconception may derive from the formula of sodium chloride (NaCl). The formula suggests that sodium chloride consists of only a sodium and chloride ion in a 1:1 ratio. In fact, the formulas of ionic compounds—similar to that for covalent network substances—do not express the total number of atoms, but their formulas express relative numbers within the compound. The formula of an ionic compound refers to the relative number of cations and anions in its lattice. For example, the formula NaCl means that there is a 1:1 ratio of Na⁺ cations and Cl⁻ anions—not separate molecules, each of which contain only one Na atom and one Cl atom (Mahaffy et al., 2011).
The process of attraction between the oppositely charged ions is called ionic bonding. It is not possible to write all of the actual atoms of sodium and chloride in a single formula. Therefore, the formula of NaCl is an empirical formula that gives the simplest ratio of the number of atoms for each element present in an ionic compound.

Another misconception may arise from student observations of salt. Salt looks like a white crystal. During interviews, one of the students seemed to incorrectly believe that salt is a single lump, as in 1 NaCl, rather than many Na⁺ and Cl⁻ ions. Below is a representative comment from a student about this misconception:

_Interviewer:_ From your drawing, does your picture look like a lump of sodium chloride?

_Tida:_ Yes, it does.

Note: Here and elsewhere where student names are used, the names are pseudonyms only.

One can conclude that at least part of the reason for pre-test misconceptions is confusion between the symbolic level—the formula of a substance (NaCl)—compared to what is observed about the physical properties of salt.

Interestingly, after learning with the molecular level visualisation approach, students still had a misconception about the arrangement of ions in solid sodium chloride. Results obtained from post-test answers showed that sodium ions and chloride ions were separated from each other (see Figure 5.34). Interviews revealed that students held a misconception about the arrangement of sodium chloride in a solid state from the animation, and thought Na⁺ and Cl⁻ are not closely packed:

_Interviewer:_ Tell me about the arrangement of sodium chloride in a solid state after viewing the animations.

_Tida:_ The particles of Na⁺ and Cl are vibrating and alternating.

_Interviewer:_ Do you think there are differences about how you thought about the arrangement of sodium chloride before and after viewing the animations?

_Tida:_ There are differences.
Interviewer: Like what?

Tida: Before seeing the animations, I thought the particles are close together, not vibrating. However, after viewing the animations, I know they are moving, vibrating and they are not close together. They are separated from each other.

In fact, sodium ions and chloride ions in a solid state are closely packed. Although the student above had a misconception after viewing the animation, the answer also shows some other areas of improvement in overall understanding. For example, the student understood that moving and vibrating occurs at the molecular level. This result—shared in similar fashion in other interviews—confirms generally the following points: 1. The teacher has to pay attention to possible areas of confusion when applying animations, otherwise the animations can contribute to potential student misconceptions; 2. Students have to have a prior knowledge about the animation topic and its key features to reduce misconceptions; and 3. Students have to have prior knowledge about the formula of substance and chemical bonding.

Although some students had misconceptions, other data suggested a broader improvement. Fifty-one percent of students displayed correct answers after using the molecular level visualisation approach (see Figure 5.35).

![Figure 5.35. Pre-test and post-test drawing of one student for the arrangement of ions in solid sodium chloride](image)

The Figure 5.35 pre-test drawing shows that this student—like other students—had a misconception about the arrangement of ions in solid sodium chloride. The student drew groups of sodium chloride, and each group consisted of 1 sodium atom with 4 chlorine atoms, and the groups are separated from each other.
This misconception may be from the physical properties of salt that students can see with the naked eye, i.e., lump materials. Below is a representative comment from a student about this misconception:

*Interviewer:* Tell me about the arrangement of sodium chloride in a solid state before viewing the animations.

*Sucha:* They will be combined to be a group, and the picture that I drew was a lump of sodium chloride.

However, after learning with the molecular level visualisation approach, the post-test drawing (see Figure 5.35) showed that students could draw the arrangement of sodium chloride correctly such as Na\(^+\) and Cl\(^-\) ions being closely packed. Interviews confirmed that students had a better mental model after learning with an animation. A representative exchange is below:

*Interviewer:* After viewing the animations, what do the animations tell you about the arrangement of sodium chloride?

*Sucha:* The arrangement of sodium chloride in a solid state is close together and ordered, for example, Na\(^+\) and Cl\(^-\) are alternating.

*Interviewer:* Do you think there are differences about how you think about the arrangement of sodium chloride before and after viewing the animations?

*Sucha:* So different.

*Interviewer:* How?

*Sucha:* After learning with the animations, there are many ions of Na\(^+\) and Cl\(^-\), they are close together, alternated and ordered. Before viewing the animations I thought sodium chloride consisted of only two atoms of Na\(^+\) and Cl\(^-\).

This exchange tends to confirm that the animation could help students achieve a positive mental model change after applying the molecular level visualisation approach. Figure 5.36 is a still slide from the animation that could help students achieve a positive mental model change.
Figure 5.36. The arrangement of sodium chloride in a solid state as depicted in a VisChem animation.

Figure 5.36 shows the arrangement of ions in solid sodium chloride where the sodium ions and chloride ions are closely packed and ordered. However, this figure shows spaces between the particles. The spaces might be confusing to students, and student drawings and interviews revealed that many students believed that the particles are not closely packed.

**Key Feature 2:** Na\(^+\) and Cl\(^-\) ions are closely packed and ordered in solid sodium chloride.

Key Feature 2 was used to assess whether students understood that sodium and chloride ions are not only closely packed, but also that the particles have to be ordered. Some students had a misconception about the particles being ordered.

No students answered correctly in the pre-test. Sixteen students (46%) had an incorrect answer both in the pre-test and post-test (see Figure 5.37).

*Figure 5.37.* Pre-test and post-test drawing by one student of the arrangement of ions in solid sodium chloride
Figure 5.37 shows that the student had a misconception in the pre-test drawing, and still had a misconception in the post-test drawing. Although the student correctly drew the particles of sodium chloride as closely packed in the post-test, the student had a misconception about the ordering of the particles. The student interview confirmed this misunderstanding about the ordering of the particles:

*Interviewer*: Do you know what NaCl is?

*Kamo*: I don’t know.

*Interviewer*: Do you know salt? NaCl is the salt in your kitchen.

*Interviewer*: Tell me your understanding about the arrangement of sodium chloride before viewing the animations.

*Kamo*: The particles of sodium chloride are not close together. They are separated a little bit from each other.

*Interviewer*: Tell me your understanding about the arrangement of sodium chloride after viewing the animations.

*Kamo*: After viewing the animations, the particles are close together. But the animations are not clear, and the particles are moving around. There are so many circles.

After viewing the animation (and other static visualisations), the student who was interviewed still had a misconception about the formula for sodium chloride (NaCl), and also had a misconception about the arrangement of ions in solid sodium chloride. For example, the student incorrectly believed that the particles are not closely packed. During the interview, the student provided other illuminating comments about limitations with the animation. The student noted that the animation was not clear, that the particles were moving around, and that the particles had many circles that apparently confused her.

In Key Feature 2, some student mental models changed after learning with the molecular level visualisation approach. Nineteen students (54%) went from incorrect pre-test answers to correct post-test answers (see Figure 5.38).
Figure 5.38. Pre-test and post-test drawing by one student of the arrangement of ions in solid sodium chloride

In the pre-test drawing, the student drew the particles of sodium chloride with squares instead of circles. The student may have thought that the physical property of sodium chloride, or salt, is a crystalline. Therefore, the student drew the particles as squares, the same as salt that can be seen in everyday life (observable level). Post-visualisations (animation, picture, etc.), the student had a better mental model of the arrangement of sodium chloride and seemed to have a better understanding that the particles are closely packed and ordered. The data from student interviews confirms a positive role for the animation, and tends to confirm the importance of teacher guidance:

*Interviewer:* Tell me about the arrangement of sodium chloride after viewing the animations.

*Nata:* They are close together and ordered. The animation helps me to understand, for example, I can see the particles are close together and vibrating. The teacher provided additional explanation by drawing pictures and diagrams on the blackboard, and that helped me to understand better. The teacher helped a lot because the animation was very fast.

**TOPIC 2: Sodium Chloride in Liquid State**

Students were asked to draw and explain the arrangement of the particles in melted sodium chloride. Student demonstration of Key Feature 3 was evaluated to
indicate whether the student had a correct mental model of melted sodium chloride after using the molecular level visualisation approach.

**Key Feature 3**: In melted sodium chloride, the ions are not so closely packed, and water molecules are not involved.

Eight students (23%) displayed correct answers both in the pre-test and in the post-test. No students who displayed a correct answer in the pre-test changed to an incorrect post-test answer. Only one student (3%) showed incorrect answers in the pre-test and in the post-test. Twenty-six students (74%) went from incorrect answers in the pre-test to correct responses in the post-test (see Figure 5.39).

![Pre-test](image1.png)  ![Post-test](image2.png)

*Figure 5.39. Student drawings of the arrangement of ions in melted sodium chloride*

In the pre-test drawing above, the student had a misconception about the arrangement of the ions in melted sodium chloride. This student, and other students, drew sodium and chloride ions as not separated from each other. However, after learning with the molecular level visualisation approach, students had a correct mental model of melted sodium chloride, i.e., that $\text{Na}^+$ and $\text{Cl}^-$ ions are separated from each other without water.

Interviews with students confirmed that the animation helped to clarify the nature of melted sodium chloride:

**Interviewer**: Tell me about the melting of sodium chloride before viewing the animations.

**Nita**: I think, $\text{Na}^+$ and $\text{Cl}^-$ are closely paired, and each pair will be separated from each other.
Interviewer: Tell me about the melting of sodium chloride after viewing the animations.

Nita: The particles are separated from each other.

Interviewer: Are melting and dissolving the same thing?

Nita: I think they are different. Ummm, the same. For sure there is water in the dissolving.

Interviewer: Tell me, do you still remember this topic from the animations? What do animations tell you about melting?

Nita: Yes, I do. For melted sodium chloride, the particles are vibrating, moving, and then are separated from each other.

The student in this interview displayed an understanding about the difference between melting and dissolving, such as water being involved in the dissolving process. The student also seemed to understand qualities about the melted sodium, such as the particles being separated from each other, vibrating and moving. The animation on this topic can be attributed to an improved understanding (see Figure 5.40).

Figure 5.40. The arrangement of ions in melted sodium chloride as depicted in a VisChem animation

**TOPIC 3: Sodium Chloride in Solution**

Four key features were used to assess whether students had a correct mental model after learning with the molecular level visualisation approach on the topic of sodium chloride in solution.
**Key Feature 4:** Na\(^+\) and Cl\(^-\) ions are separated from each other in dissolved sodium chloride.

Ten students (28%) gave correct answers both in the pre-test and in the post-test. Although many students gave a correct answer, students still had a misconception about dissolved sodium chloride, such as incorrectly believing that the size of sodium chloride will decrease after dissolving.

Three students (9%) showed correct answers in the pre-test and incorrect answers in the post-test. Seven students (20%) gave incorrect answers both in the pre-test and in the post-test (see Figure 5.41).

![Pre-test and Post-test drawings](image)

*Figure 5.41.* Student drawings of the arrangement of ions in dissolved sodium chloride

Figure 5.41 showed that the student drew sodium similarly in the pre-test and in the post-test. The result suggested that the student still had a misconception about dissolved sodium chloride. The interview below provided some clues about possible sources of the misconception, including the student’s apparent low prior knowledge, and not paying attention in class:

*Interviewer:* What is the name of NaCl?

*Yad:* I don’t know

*Interviewer:* It is sodium chloride or salt in your kitchen.

*Interviewer:* After viewing the animations, can you explain about dissolved sodium chloride?

*Yad:* I don’t remember because while the teacher was teaching I didn’t pay attention in the class.
Interviewer: Why do you still have misconceptions before and after viewing the animations?

Yad: I didn’t pay attention in the class.

Fifteen students (43%) had incorrect pre-test responses, and correct responses in the post-test (see Figure 5.42).

![Pre-test and Post-test drawings](image)

**Figure 5.42.** Student drawing of the arrangement of ions in sodium chloride

The pre-test drawing in Figure 5.42 incorrectly shows the sodium ion and chloride ion as paired together. The student may have thought that sodium chloride ions are separated from each other but still paired. However, after learning with the molecular level visualisation approach, the student drew positive and negative ions separated from each other and surrounded by water molecules. In addition, the oxygen atoms in the water molecules face towards the Na\(^+\) ions, and the hydrogen atoms in the water molecules face towards the Cl\(^-\) ions. Below is a representative comment from a student:

*Interviewer: Are dissolving and melting the same?*

*Amon: Umm, I think they are the same, umm I am not sure.*

*Interviewer: Tell me, what is different before and after viewing the animations about dissolved sodium chloride?*

*Amon: After viewing the animation, Na\(^+\) and Cl\(^-\) ions are separated from each other, and I can see that each ion is surrounded by water molecules. So dissolving involves water but melting does not involve water.*

**Key Feature 5:** Na\(^+\) and Cl\(^-\) ions are separated from each other, and each ion is surrounded by water molecules, in sodium chloride solution.
This key feature is similar to Key Feature 4, but tests whether students understand that each ion is surrounded by water molecules. This key feature was added because some students drew ions that are separated from each other, but they did not draw any water molecules. In fact, the water molecules are an essential component of the solution because water solvates the ions resulting in ions being separated from each other before sodium chloride changes to be sodium chloride solution. Therefore, drawing dissolved sodium chloride with water molecules is an important check on student deep understanding at the molecular level.

No students gave correct answers in the pre-test and in the post-test. No students who correctly answered in the pre-test changed to an incorrect answer in the post-test. Eight students (23%) had incorrect answers both before and after using the molecular level visualisation approach (see Figure 5.43).

![Figure 5.43. Student drawings of the arrangement of ions in dissolved sodium chloride](image)

The pre-test drawing from Figure 5.43 shows sodium and chloride ions are paired together. The post-test drawing shows each ion is separated from each other, but water molecules are not depicted. It seems that this student retained misconceptions about dissolved sodium chloride before and after learning with the animation. Interviews suggest student attention, and their prior knowledge, might have had at least a partial influence on some of the answers:

*Interviewer*: Tell me about the dissolved sodium chloride before and after viewing the animation.

*Saran*: I think, sodium ions and chloride ions are closely packed. After viewing the animation, I saw molecules of water but I forgot to draw
water molecules because I did other homework in the classroom.

Other results showed that student mental models changed after using the molecular level visualisation approach. Twenty-seven students (77%) gave incorrect answers in the pre-test, and correct answers in the post-test (see Figure 5.42).

*Interviewer:* Tell me about sodium chloride solution after viewing the animations.

*Sucha:* Water will make sodium and chloride ions separate from each other. Negative ions from water will face towards Na+, and positive ions will face towards Cl−.

*Interviewer:* What is a negative ion from water?

*Sucha:* Hydrogen.

*Interviewer:* How many oxygen atoms are in a water molecule?

*Sucha:* Two atoms.

*Interviewer:* Really?

*Sucha:* Oh. Only one atom.

*Interviewer:* What do you think about animations?

*Sucha:* It is not clear. I am not sure about what kind of ion from a water molecule faces towards sodium and chloride ions. I don’t know. It is not clear.

Although many students had a correct mental model after applying the molecular level visualisation approach, interviews revealed that students were still confused about the charge of ions. For example, students said the hydrogen ion is a negative ion. In fact, a hydrogen ion is a positive ion. Another misconception is the number of atoms of oxygen from a water molecule. The student in the interview above said both two atoms and one atom. The low prior knowledge about the correct formula for a water molecule probably negatively affected the learning process. However, the learning process could accommodate this issue by having the teacher explain the building block of the water molecule by reference to the animation.
**Key Feature 6:** The oxygen atoms in water molecules face towards the Na\(^+\) ions in sodium chloride solution

No students answered correctly in the pre-test. Fifteen students (43%) had incorrect answers both in the pre-test and in the post-test (see Figure 5.44).

![Pre-test and Post-test drawings](image)

*Figure 5.44. Student drawing of the arrangement of ions in sodium chloride solution*

This key feature is designed to check whether students had a proper understanding that oxygen atoms in the water molecules will face towards the sodium ions. Although the pre-test drawing in Figure 5.44 showed that ions are separated from each other, the post-test drawing still showed a misconception with oxygen atoms in the water molecules facing towards the chloride ion. Perhaps students were confused about the charges in each ion of the water molecules. At least one interview suggested this very issue:

*Interviewer:* Tell me about dissolving sodium chloride in water.

*Vani:* When I added water into sodium chloride, it will dissolve. I think, sodium and chloride ions are separated from each other. However, after viewing the animations, I understood that sodium and chloride ions are surrounded by water molecules. The hydrogen ion, the positive ion from water molecules, will face towards the sodium ions.

*Interviewer:* What kind of charge does hydrogen have?

*Vani:* Umm, negative charge. I think, the animations are very fast, so I could not see the animations clearly, for example, when the water molecules pulled the ions from sodium chloride.
This student still had misconceptions because she was confused about the charge of the hydrogen atom. The student also felt that the animation was too fast, and therefore was hard to understand.

Although some students had misconceptions, twenty students (57%) displayed correct answers after using the molecular level visualisation approach. Below is a representative comment:

*Nita:* I think, in dissolved sodium chloride, sodium ions and chloride ions are separated from each other, but after viewing the animations, I understand there are surrounding molecules of water. Water molecules made the sodium and chloride ions separate from each other, and each ion is surrounded by water molecules.

*Interviewer:* In your opinion, are animations alone sufficient to help you understand the topic?

*Nita:* No, so, I understand because the teacher helped to explain by drawing the pictures and diagrams on the blackboard, and friends helped too.

The above response was representative of other responses, and indicates a place for animation to help explain dissolved sodium chloride as part of a broader teaching framework involving teacher guidance and use of static visualisations to complement, or supplement, the animation. A still frame from the VisChem animation that could help explain this key feature is shown in Figure 5.45 below:

*Figure 5.45.* The arrangement the particles in dissolved sodium chloride as depicted in a VisChem animation
Although animations can play an important role in chemistry teaching, the results so far seem to suggest that the animations, standing alone, will probably not be sufficient. The teacher needs to appropriately introduce the topic, and guide the students with explanations, drawings, and pictures.

**Key Feature 7:** The hydrogen atoms in water molecules face towards the Cl\textsuperscript{−} ions in sodium chloride solution

No students gave correct answers in the pre-test. Seventeen students (49%) had incorrect answers in both the pre-test and in the post-test. Students therefore held misconception before and after using the molecular level visualisation approach. Eighteen students (51%) went from incorrect answers in the pre-test to correct responses in the post-test, showing some positive results for the molecular level visualisation approach. Below is a representative comment from a student:

*Interviewer:* Tell me about before and after viewing the animations.

*Nata:* Umm. Before the animation I did not think there are water molecules in dissolved sodium chloride, so I didn’t draw water molecules. Sodium and chloride ions are separated from each other. However, after viewing the animation, I understand that ions are separated from each other and positive ions from the water molecule face towards the chloride ions. And oxygen from water molecules faces towards the sodium ions.

The interview again suggested a place for animations to help students better understand this key feature.

**TOPIC 4: Silver Nitrate Solution**

The silver nitrate solution topic is similar to the sodium chloride solution topic. However, students were asked to draw and explain the arrangement of silver nitrate solution. For the topic of silver nitrate solution, Key Features 8 to 11 are described below.

**Key Feature 8:** Ag\textsuperscript{+} and NO\textsubscript{3}\textsuperscript{−} ions are separated from each other in silver nitrate solution.
Eight students (23%) had a correct answer in both pre-test and post-test. Six students (17%) gave a correct answer in the pre-test, and an incorrect answer in post-test. Only four students (11%) gave incorrect answers in both the pre-test and post-test. Below are some brief comments from one student:

*Interviewer:* What is the name of AgNO$_3$?  
*Jak:* I don’t know. I copied from my friend.  
*Interviewer:* Tell me about silver nitrate solution after viewing the animations.  
*Jak:* The particles of silver and nitrate ions are separated from each other.  
*Interviewer:* That’s correct. But why is your drawing wrong?  
*Jak:* In that time, I did homework for another subject so I did not pay attention in the classroom.  

Other parts of the same interview revealed that the student could not read the name of AgNO$_3$, pointing out a low prior knowledge about the name of the substance. Before students can draw and explain at the molecular level correctly, students have to have at least a basic understanding about the concept of chemistry as represented by symbolic formulas. Although some students still had misconceptions about silver nitrate solution, seventeen students (49%) gave an incorrect answer in the pre-test, and a correct answer in the post-test, which suggested an improvement in their understanding. Figure 5.46 is an illustration of this improvement:

![Pre-test and Post-test drawings](image)

*Figure 5.46.* One student’s drawings on the arrangement of ions in silver nitrate solution

The pre-test drawing (see Figure 5.46) showed the nitrate ions and silver ions connected together. This student’s drawing indicates a misconception about the
arrangement of the particles of silver nitrate solution. The post-test drawing, by
contrast, shows that the silver ions and nitrate ions are separated from each other, and
surrounded by water molecules. Below is a representative comment from a student:

*Interviewer:* Tell me about silver nitrate solution before viewing the
animations.

*Sucha:* I think, ions of silver nitrate solution are close together.

*Interviewer:* How about after viewing the animations?

*Sucha:* I think, silver nitrate solution is similar to sodium chloride solution. Water molecules pulled the ions from the solution, and made silver
and nitrate ions separate from each other. However, I think, the
animations were not clear, too fast. The teacher helped to explain by
using a picture and diagram, and I could understand better then.
Seeing only the animations did not help me to understand.

Animations combined with pictures and diagrams appears to have helped the
student understand the arrangement of silver nitrate solution clearly. Part of the
animation that could help students understand this key feature is shown in Figure
5.47 below. Data obtained relating to this key feature, like those before, highlight
certain potential drawbacks of animations such as the audio not being clear enough,
being too fast, and requiring teacher guidance before and after the animation to guide
students about what specifically to look for as the animation plays. Students
frequently made such observations during interviews, and with reference to the
building blocks of silver nitrate solution shown below.

![Building blocks of silver nitrate solution](image)

*Figure 5.47.* The building blocks of silver nitrate solution as depicted in a
*VisChem* animation
**Key Feature 9:** Ag\(^+\) and NO\(_3\)\(^-\) ions are separated from each other, and each ion is surrounded by water molecules, in silver nitrate solution.

Key Feature 9 is similar to Key Feature 8. However, students were asked to draw and explain the arrangement of silver nitrate solution adding another element, i.e., that the particles are surrounded by water molecules.

No students gave correct answers in the pre-test. Four students (11%) had incorrect answers both in the pre-test and in the post-test. Other results showed that students’ mental model changed after using the molecular level visualisation approach. Thirty-one students (89%) gave incorrect answers in the pre-test, and the correct answer in post-test. Below is a representative comment from a student:

*Interviewer:* Tell me about silver nitrate solution before and after viewing the animations.

*Pani:* Before viewing the animation, I thought that ions are separated from each other without molecules of water, but after viewing the animation, silver and nitrate ions are separated from each other and surrounded by water molecules.

This kind of general comment was repeated in other interviews, and tends to confirm an important role for using animations to reveal this key feature to students. The large improvement in post-test results indicates that the animation was successful in revealing the particulate nature of silver nitrate solution. The improvement could also potentially be attributed to the fact that an animation about sodium chloride solution preceded the animation about silver nitrate solution, and students may have recognised the similar arrangement of the particles in the solution.

**Key Feature 10:** The oxygen atoms in water molecules face towards the Ag\(^+\) ions in silver nitrate solution.

No students correctly answered in the pre-test. Thirteen students (37%) gave incorrect answers both in the pre-test and in the post-test. Twenty-two students (63%) gave incorrect answers in the pre-test and correct answers in the post-test, suggesting a mental model change after using the molecular level visualisation approach. Below is a representative comment from a student:
Interviewer: Tell me, how is your understanding different after viewing the animations?

Nita: Before viewing the animation, I thought ions from silver nitrate solution are separated from each other. After viewing the animation, I understand that not only are ions separated, but also that the ions are surrounded by water molecules, and that oxygen from water molecules faces towards the silver ions.

Key Feature 11: The hydrogen atoms in water molecules face towards the NO$_3^-$ ions in silver nitrate solution.

No students correctly answered in the pre-test. Fourteen students (40%) had incorrect answers both in the pre-test and in the post-test (see Figure 5.48). Sixty percent improved from incorrect answers in the pre-test to providing correct answers in the post-test.

![Pre-test](image1.png) ![Post-test](image2.png)

Figure 5.48. Student drawings of the arrangement silver nitrate solution, hydrogen from the water molecules did not face towards the nitrate ions (misconception)

The student’s post-test drawing in Figure 5.48 was more accurate that the pre-test drawing. For example, the student drew the nitrate and silver ions as being separated from each other and surrounded by water molecules. However, other students retained misconceptions such as when they showed the hydrogen atoms in the water molecules as not facing towards the nitrate ions. Below is a representative comment from a student:

Interviewer: Do you think that aqueous and liquid are the same?

Ora: No, they are different, but I have never heard of “aqueous” before.

Interviewer: Tell me about silver nitrate solution after viewing the animation.
Ora: Nitrate is a negative charge. Hydrogen atoms in water is a positive charge, so they will face towards the nitrate ions.

Although the student explained correctly the charges of the nitrate ion and the hydrogen atom in water molecules, this student’s drawing did not match the interview description. However, the interviewer did not ask the student why the drawing was different from what the student described during the interview.

Other results showed that students’ mental model changed after using the molecular level visualisation approach. Twenty-one students (60%) who gave an incorrect answer in the pre-test gave correct answers in the post-test. The results were similar to Key Features 8 to 11 with the topic of silver nitrate solution where the group of students who improved from incorrect to correct responses was larger than for the other groups.

**TOPIC 5: Precipitation**

Students were asked to draw and explain the arrangement of the particles after mixing a solution of sodium chloride and silver nitrate solution. Students’ drawings were marked with reference to Key Features 12 to 14, and are described below.

**Key Feature 12:** Silver ions and chloride ions are closely packed in silver chloride precipitate.

No students had correct answers both in the pre-test and in the post-test. Only one student (3%) gave a correct answer pre-test but later changed to provide an incorrect answer in the post-test. Twenty students (57%) gave incorrect answers both in the pre-test and in the post-test (see Figure 5.49). Forty percent of the students improved from providing initially incorrect answers in the pre-test to correct answers in the post-test.
These student drawings (see Figure 5.49) show the particles as being separated from each other, which is not correct. The interview responses suggested, again, that the speed of the animation may be a cause for this misconception:

*Interviewer:* Tell me about silver chloride precipitation.

*Chuti:* I think, the animations were very fast, so I did not understand.

*Interviewer:* What do you think can help you understand better?

*Chuti:* I should see the animation more than one time.

*Interviewer:* Why do you still not understand?

*Chuti:* I didn’t pay attention in the classroom, and I could not remember the formula of silver nitrate that I already studied from Year 10.

This interview tends to confirm a general theme from student interviews in prior key features: from a student perspective, the animations move quickly, and some students do not feel comfortable with their prior knowledge. These observations, in turn, may partially explain some students admitting that they did not pay very close attention.

As noted above, forty percent of students changed from incorrect to correct responses (see Figure 5.50).
Figure 5.50. Student drawings of the arrangement of ions in silver chloride precipitate

The Figure 5.50 drawing showed that silver and chloride ions are closely packed, and the nitrate ion and sodium ion are separated from each other, and surrounded by water molecules. Student interviews tended to confirm that the animation helped the student achieve a better understanding:

*Interviewer:* What is the name of Ag?
*Nata:* I don’t know.

*Interviewer:* What is the name of NO$_3^-$?
*Nata:* I don’t know.

*Interviewer:* Tell me about after mixing sodium chloride solution and silver nitrate solution together.
*Nata:* Before viewing the animation, I thought all ions are separated from each other, but after viewing the animation, I saw a white precipitate of silver chloride. Sodium ions and nitrate ions are separated from each other and surrounded by water molecules.

*Interviewer:* What do you think made you understand?
*Nata:* I think, the teacher helped me understand more, and the teacher used pictures and diagrams too. I don’t think I understood based on the animation alone.

Although the student drew the particle of precipitation correctly, the interview revealed that the student still retained misconceptions such as the student not being able to read the name from the formula of Ag and NO$_3^-$. This student did
suggest a positive influence from the teacher’s explanations that used static visualisations such as pictures and diagrams.

**Key Feature 13:** Sodium and nitrate ions remain separated from each other after silver chloride precipitation.

Four students (11%) had correct answers both in the pre-test and in the post-test. Five students (14%) gave correct answers in the pre-test, and incorrect answers in the post-test. Seventeen students (49%) gave incorrect answers both in the pre-test and in the post-test. Only nine students (26%) went from incorrect answers in the pre-test to correct responses in the post-test. These results suggest that many students still had misconceptions before and after using the molecular level visualisation approach.

**Key Feature 14:** Sodium and nitrate ions remain separated from each other as hydrated ions after silver chloride precipitation

No students gave correct answers in the pre-test. Twelve students (34%) had incorrect answers both in the pre-test and in the post-test. Some student answers changed from incorrect to correct after the molecular level visualisation approach. Twenty-three students (34%) gave incorrect answers in pre-test and correct answers in post-test. Below is a representative comment from a student:

*Interviewer:* Tell me your understanding after viewing the animation on the topic of mixing silver nitrate solution and sodium chloride solution together.

*Pani:* Chloride ions will stick with silver ions, and will change to be a precipitate of silver chloride. Nitrate and sodium ions are separated from each other and surrounded by water molecules.

This student interview suggested that the animation could help the student better understand about the arrangement of the particles in precipitation.
5.4 Discussion

Phase II of this research compared results about student understanding after the students were taught in three different ways: a traditional approach, a traditional approach incorporating animations, and a seven-step molecular level visualisation approach. A summary of the interpretations of Phase II results are provided below, and developed in additional detail in Chapter 6.

5.4.1 Traditional Approach

How Did the Teacher Teach and Students Learn Chemistry with the Topic of Dissolving Sodium Chloride in Water Using the Traditional Approach?

The details of the teaching and learning process are as detailed in Section 5.1.1. The traditional approach was teacher-centred—most of the teaching occurred by the teacher with students as passive listeners. General initial explanation of a topic was followed by laboratory experiment (if materials were available), then followed by further explanation by the teacher. The teacher might refer during the explanation step to textbook diagrams or other static models, as well as introducing the associated chemical equations and calculation step.

There have been three notable features of this approach: (1) no particular use or discussion relating to the molecular level; (2) no peer-to-peer component or other active role for students; (3) little consideration given to how quickly information was provided to students.

At its broadest level, the teacher-centred approach described above is giving way to alternate theories of teaching where a more active student role is envisaged (Waldrop, 2015).

Each element above is susceptible to modification in teaching style. Where resources exist, animations can be incorporated with the goal of introducing the molecular level. Students can be broken into groups and given explicit tasks by way of notetaking, and such results can be compared on a peer-to-peer basis. More
thought can occur regarding how quickly, and in what manner, the information is presented. Generally stated, these changes would enable linking between the three levels of thinking—observable, molecular, symbolic. Peer-to-peer work, meanwhile, advances the general goal of transforming classrooms from teacher-centred to student-centred, consistent with educational goals for Thailand (and now for most of the world). Finally, how and in what manner information is presented is a central tenet of the information processing model (see Section 2.3). Increased focus on key elements, repeating the animation, and providing opportunities for notetaking and peer to peer discussion all heighten the chance for effective student processing of information. A sample classroom syllabus incorporating all of these elements is presented in Section 6.5.

**Does This Approach Help Students Achieve a Deep Understanding of Particular Concepts in Chemistry?**

Pre-test and post-test multiple choice test results after using this approach were not significantly different ($p=.50$). The average results from the calculation tests, meanwhile, showed that no students (0%) held a sound understanding, and only 10% of students had a partial understanding with misconception, and 90% of students still held specific misconceptions. The test results of students exposed to traditional classroom methods highlight some limitations of that approach. Application of a traditional approach to teaching chemistry resulted in a variety of student misconceptions relating to (1) the chemical formulas; (2) balancing the chemical equations; (3) writing the state of substance; and (4) confusing the terms ion, atom and molecule.

After traditional chemistry teaching, students could not write the chemical formula correctly. For example, some students wrote $\text{Mg(s)}$ for the chemical formula of magnesium chloride instead of $\text{MgCl}_2$. Without the ability to correctly write the chemical formula, students will not be able to connect to new knowledge because the chemical formula is the basic building block of chemical substances. Student difficulties with writing chemical formulas have been confirmed by prior research. For example, Dahsah (2007) found that Thai secondary students gave a
wrong formula of the expected solid product such as SrPO$_4$ and Sr(PO$_4$)$_2$. In fact, the correct chemical formula is Sr$_3$(PO$_4$)$_2$.

Students also had difficulty balancing chemical equations after traditional instruction. Failure to master this skill leads to ongoing problems in learning chemistry. A balanced chemical equation is one that satisfies two requirements: 1) The total electrical charge on the reactant chemical(s) is equal to the total charge on the product chemical(s). 2) The chemical equation must be consistent with the law of conservation of atoms (Mahaffy et al., 2011, p.117-118). Some research studies showed that students ignore balancing of chemical equations. For example, Haidar (1997), Furio, Azcona and Guisasola (2002), and Dahsah (2007) found that students failed to balance the equation and students used a 1:1 mole ratio for all substances in the equation. Dahsah (2007), and Howe and Johnstone (1971), meanwhile, found that students did not try to construct formulae from first principles, but simply memorised the ones most commonly used. Similar results were obtained for writing balanced equations: memory was used, and the answers were not supported by correct reasons. The Phase II results tend to confirm these students’ problem with balancing chemical equations.

A third common misconception we found during Phase II was the state of substance. Students incorrectly wrote the state of aqueous (aq) as (aa) or (qq). Students did not appear to understand the meaning of the aqueous solution. Some research studies have identified the state of substance as being a problem for students when writing the chemical equation. For example, Smith and Metz (1996) found that students failed to write the state of substance as (s) for solid, (l) for liquid, and (aq) for aqueous. Moreover, Kelly et al. (2010) found that students simply do not understand the meaning of aqueous represented as “aq”, or they do not consider it to be important.

Students in this research also seemed to be confused about the differences between the terms ion, atom and molecule. For example, students wrote chloride ion in the chemical equation as Cl, or Cl$_2$, instead of Cl$^-$. Some research studies identified the same result. For example, Barke (2012) found that students do not distinguish between ions, atoms and molecules of O$^{2-}$, O and O$_2$.
How Do Students’ Mental Models Change after Using this Approach?

For the mental model change, meanwhile, the average results from the drawing tests showed that 73% of students had incorrect answers both in the pre-test and in the post-test (XX), and only 12% of students had incorrect answers in pre-test and correct answers in post-test (X/). Students therefore still had a misconception before and after using the traditional approach.

The drawing tests revealed several misconceptions, described below.

(1) Many students drew the arrangement of sodium chloride in a solid state with the sodium and the chloride ions paired together. This misconception might arise from not understanding what the chemical formula of sodium chloride (NaCl) means. The chemical formula shows only one atom of sodium (Na) and one atom of chlorine (Cl). Therefore, students drew the arrangement of sodium chloride with sodium and chloride atoms/ions as being paired together. This is why it is important to show students the structures of ionic compounds, and to point out the relative ratios of the ions present, and how this is summarised by the chemical formula.

Other research studies pointed out the same student misconception about ionic solids dissolving as neutral ion-pairs—for example, students incorrectly believe that in water, NaCl ion pairs do not break apart (Butts & Smith, 1987; Jansoon et al., 2009; Kelly & Jones, 2007; Kelly et al., 2010; Liu & Lesniak, 2006; Smith & Nakhleh, 2011; Tien et al., 2007).

Using the traditional approach, students had difficulty making connections between the symbolic level and the molecular level. Kelly et al. (2010) explored the nature of the molecular level understandings as shown in student drawings and explanations. The findings indicated that students were unclear about the nature of ionic compounds. Many students seemed confused about the workings of the molecular level if the teacher tends to use only symbolic and observable levels. The results described by Kelly et al. (2010) suggested that teaching chemistry to students with only two levels may create confusion about what is happening at the molecular level. Using the molecular level visualisation approach should help students better
understand at the molecular level, and can also help to link the three levels of thinking.

(2) Many students drew the arrangement of ions in melted sodium chloride with water molecules. This is a common misconception as has been shown by, for example, Haidar and Abraham (1991), Liu and Lesniak (2006), and Smith and Nakhleh (2011). The results suggested that students were confused about the processes involved in dissolving and melting of ionic substances after traditional teaching methods. This result reinforces the need for students to visualise the difference at the molecular level.

(3) Some students drew only water molecules for sodium chloride solution because it is clear and colourless like water. Student confusion derived in part from observable physical properties has been broadly recognised. Badrian et al. (2011), Stojanovska et al. (2012), and Yakmaci–Guzel (2013) all found that students held the misconception that atoms and molecules have macroscopic properties. For example, that atoms and molecules expand as an explanation for increasing substance volume as when a substance is heated.

(4) The test results showed possible misconceptions arising from confusion between symbolism and the Thai language. The silver nitrate solution drawings showed that some students drew the particles of the silver ion as being inside the nitrate ion. “Ni” in Thai language means “inside.” It is possible, therefore, that students had a language based misconception. Language based misconceptions have also been generally recognised in other research. For example, Johnstone and Selepeng (2001) found that students whose first language was not English had problems with learning science. In their study, they used a series of words common in the science classroom, and multiple choice tests were administered to determine if the students understood the words. Both native English speakers and speakers from other language backgrounds participated. The results were “alarming” because non-native English speakers displayed a wide range of misunderstandings (Johnstone & Selepeng, 2001, p. 21). The researchers suggested that the process of translating, or holding information in unfamiliar form, reduced available working space memory. The report concluded a loss in available working space of “just over 25%” for the
average non-English speaking student (Johnstone & Selepeng, 2001, p. 25) (see Figure 5.51).

Figure 5.51. Loss of working space when using a second language (Johnstone, 2006, p. 58)

Figure 5.51 was taken from Johnstone (2006), and he was reporting on work from other researchers that indicate that working space/memory has a limited capacity. For complex tests, like counting backwards with digits (reverse-digit testing), some of that limited working space is used to process the complex information. Second language speakers use part of the space not only for the complex information they are processing (such as one would use for “reversing”), but also for translating. Effectively, then, second language speakers have less working space memory with which to process the new chemical education information.

The overall test results for the traditional teaching methods tend to cast doubt on how effective those methods are. The multiple choice transfer test showed that post-test scores were not significantly different from the pre-test score, and the result from the calculation test showed that 90% of students still had a specific misconception, and the result from the drawing test showed that 73% of students still had a misconception before and after using the traditional approach.
5.4.2 Incorporating Animations with the Traditional Approach

How Did the Teacher Teach and Students Learn Chemistry with the Topic of Dissolving Sodium Chloride in Water Incorporating Animations with the Traditional Approach?

The in-class teaching and learning was similar to Class A (traditional approach), and was described in Section 5.2.1. The important component added was to include animations. The animations were incorporated in the classroom at the “explanation step.” The explanation followed conclusion of the initial class discussion and small group experiments.

When the animation was presented, it was presented one time. The teacher assisted the class after the animation was presented by drawing pictures and diagrams on the blackboard. Students, by contrast, were not required independently to make drawings of their own conceptions of the molecular level, or to actively engage in construction of their own understanding of molecular level events by discussion with peers, or otherwise.

A positive aspect of this approach was complementing the animation with static diagrams. Students during this research repeatedly expressed that the post-animation discussion by the teacher was helpful.

Another positive aspect of this approach was that linking among the three levels of thinking was enabled. In particular, the animation explicitly introduced the workings of the molecular level to supplement the observable and symbolic levels.

A primary drawback of this approach: arguably too much information was presented too fast. Animations can be overwhelming in their detail (Kelly & Jones, 2007). Presenting the animation multiple times is therefore advisable (Tasker & Dalton, 2008). Individual key elements were not discussed while the animation was playing. Unnecessary information can quickly put students in an information overload situation (Reid, 2008). In essence, a lot of information was presented quickly and without much time for student reflection. A more careful stepwise
approach allowing for more reflection is presented, by way of juxtaposition, in Section 6.5.

**Does This Approach Help Students Achieve a Deep Understanding of Particular Concepts in Chemistry?**

Class B incorporated animations into a traditional instructional approach to teach chemistry. There was no significant difference between the pre-test and post-test results ($p=.39$). The results were roughly similar to those described above for the traditional approach. However, the average post-test mean score after using animations with the traditional approach (3.68) is still higher than the average post-test mean score of the traditional approach (3.10).

For the calculation test, the average results for all key features showed that only 14% of students had a sound understanding. No student could be classified as having a partial understanding, but 35% of students had a partial understanding with some misconception; and 51% of students still had a specific misconception. Students’ misconceptions were similar to misconceptions discussed above for Class A (traditional approach), that is, misconceptions about chemical formulas, chemical equations, the state of a substance, and the difference between the terms ion, atom and molecule. However, after comparing the results on specific key features between Class A and Class B, some differences appeared. The results suggested that more students had a sound understanding when animations were incorporated than when exposed to traditional teaching methods alone. Furthermore, more students had specific misconceptions in Class A. Incorporating animations appeared to help students better understand at the molecular level in chemistry than teaching with the traditional approach alone.

**How Do Students’ Mental Models Change after Using this Approach?**

For the mental model change, the average results for all key features from the drawing test showed that 58% of students had incorrect answers in both the pre-test and in the post-test (XX), and only 27% of students had incorrect answers in the pre-test and correct answers in the post-test (X/). The percentage of students who had
incorrect answers both in the pre-test and in the post-test (XX) in Class A (73%) was higher than for Class B (58%), and the number of students who had incorrect answers in the pre-test and correct answers in the post-test (X/) from Class B (27%) was higher than for Class A (12%). Although 27% of students displayed correct answers after viewing the animation, 58% of students still had misconceptions before and after using this approach.

Many kinds of misconceptions were revealed by the drawing tests. Some of the misconceptions are similar to the traditional approach: 1) many students drew the arrangement of ions in solid sodium chloride with the sodium and the chloride ions paired together; 2) many students still drew the arrangement of the melted sodium chloride with water molecules; 3) misconceptions existed that appear to stem from the observed physical properties of a substance.

The misconceptions in Class B may be attributable, in part, to the manner in which the animations were presented. To help students understand at the molecular level, the teacher has to provide guidance about each key feature, or students’ misconceptions may persist (Tasker & Dalton, 2006). Moreover, students were not asked to draw at the molecular level before and after using animations (i.e., no reflecting on answers), and the teacher did not teach students to link between the three levels. Collectively, each of these issues likely contributed in some manner to the Class B misconceptions that remained even after using an animation.

5.4.3 The Molecular Level Visualisation Approach

How Did the Teacher Teach and Students Learn Chemistry with the Topic of Dissolving Sodium Chloride in Water Using the Molecular Level Visualisation Approach?

The details and research related to the VisChem seven-step learning design were provided in general in Section 2.4 (VisChem animation), and as applied in the classroom for this research in Section 5.3.1 (Teaching with the molecular level visualisation approach). This method, and its implications, and a suggested particularised application, are all discussed in Chapter 6.
Does This Approach Help Students Achieve a Deep Understanding of Particular Concepts in Chemistry?

The results from the multiple choice test of the molecular level visualisation approach demonstrated a significant increase from the correct responses in the pre-test to the correct responses in the post-test \((p=.00)\) (see Table 5.7). The results from one-way ANOVA showed that the pre-test score between the classes, and within the classes, is not significantly different \((p=.08)\) (see Table 5.10). The results suggested that students from three classes had the same prior knowledge before conducting this research.

The results from the post-test scores between the groups, and within the groups, showed a significant difference \((p=.00)\). These results suggested that after learning with the different approaches, students had significantly different scores (see Table 5.10). Table 5.11 compares post-test results among the various groups. The results for Class C exposed to the molecular level visualisation approach is significantly different from Class A (traditional approach, \(p=.00\)) and Class B (incorporating animations, \(p=.00\)). The results of the post-test scores between Class A and Class B were not significantly different \((p=.15)\).

### Table 5.10

*The results from one-way ANOVA of the pre-test and post-test between and within the groups*

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<tr>
<td></td>
<td>Total</td>
<td>118</td>
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*p<.05*
Table 5.11

*Comparison of the post-test mean score between the groups*

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<th>Group(J)</th>
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<td>.00*</td>
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</tr>
<tr>
<td>Traditional</td>
<td>VisChem</td>
<td>0.31</td>
<td>.15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Visualisation</td>
<td>0.32</td>
<td>0.00*</td>
<td></td>
</tr>
</tbody>
</table>

*p<.05

The multiple choice test results support the finding that the molecular level visualisation approach helps students achieve a deeper understanding than the traditional approach, or than the traditional approach incorporating animations.

For the calculation test, the average results for all key features (see Table 5.12) showed that 16% of students demonstrated a sound understanding. Eleven percent of students had a partial understanding, 65% of students had a partial understanding with misconception, and only 8% of students still had a specific misconception.

After comparing the results among three approaches, 16% from the molecular level visualisation approach had a sound understanding (SU), compared to 14% from Class B, and compared to 0% for Class A. In addition, the number of students in Class A (traditional approach) who had a specific misconception (SM) was 90%, much higher than the number of students (51%) from the Class B group (animations with the traditional approach), and even higher still than the Class C group (molecular level visualisation approach) (8%) (see Table 5.12).

Table 5.12

*Comparison of deep understanding among Classes A, B and C*

<table>
<thead>
<tr>
<th>Approach</th>
<th>SU</th>
<th>PU</th>
<th>PUM</th>
<th>SM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional</td>
<td>0</td>
<td>0</td>
<td>10%</td>
<td>90%</td>
</tr>
<tr>
<td>Animations with traditional</td>
<td>14%</td>
<td>0</td>
<td>35%</td>
<td>51%</td>
</tr>
<tr>
<td>Molecular level visualisation</td>
<td>16%</td>
<td>11%</td>
<td>65%</td>
<td>8%</td>
</tr>
</tbody>
</table>
The results from the multiple choice and calculation tests suggested that the molecular level visualisation approach helped students to develop a deeper understanding at the molecular level in chemistry more effectively than for the students in Class A or Class B. Similar results were obtained by Akpmar (2014) who applied a predict-observe-explain model. The predict-observe-explain model is similar, in some respects, to the molecular level visualisation approach because it involves a high degree of student involvement by making predictions and discussing results after observation. The author compared two approaches, one using a predict-observe-explain (POE) model with animations, and another normal approach to teaching where the teacher provided lectures, discussion and homework. The author used a pre-test and post-test on the topic of static electricity using a concept test and open-ended questions. The results suggested that the animations approach had a more positive effect on student understanding than a normal approach. In explaining the results, the author noted the importance of combining animations with pictures, figures, and graphics, and doing so as an “integrated approach” (Akpmar, 2014, p. 528-529). The benefit of the integrated approach is to create links between what can be observed and the more abstract levels. Of Class A, B and C (molecular level visualisation approach) students were exposed to a similar integrated approach that could allow active and effective linking between the three levels.

Although the results from multiple choice and calculation tests showed that students from the molecular level visualisation approach could have a deeper understanding than the other classes, the calculation results showed that students in Class C still could not solve the problem of the concentrations of ions in magnesium chloride solution and in the mixed solution. The students could not balance chemical equations correctly, a problem shared by each class during Phase II of the research. This result suggests that students had a low prior knowledge, and could not connect with the new challenge this type of problem posed. To answer such calculation questions correctly would generally require students to be able to link the observable level to the molecular level, and then to the symbolic level. If the students understood and could draw the arrangement of the particles in the solution at the molecular level correctly, then students would more likely be able to write the chemical equation and calculate the concentration of each ion correctly. The fact
that all three classes had difficulties suggests that students could not link effectively between the observable level and the molecular level and the symbolic level.

Many students tried to calculate the concentration of each ion in solution by using the formula without understanding the difference between the concepts of amount and concentration. Appropriately linking the three levels could help students solve the problem and achieve deep understanding in chemistry (Dori & Hameiri, 2003). Dori and Hameiri (2003) examined a Multidimensional Analysis System aimed at improving mole-related quantitative problem solving. The system allowed consideration of complexity levels (not a part of this research), and also required explicit use of a multi-level teaching approach. The experimental group had a much better success rate, particularly with more complex questions.

Student misunderstandings about the multi-level relationships results in misconceptions on a wide range of chemistry topics (Levy, Nahum, Hofstein, Mamlok-Naaman & Bar-Dov, 2004; Nakiboglu, 2003; Taber, 1994, 2002a). Johnstone (1993) indicated that one reason that students have difficulty learning chemistry is that they do not understand the relationships between the levels, especially when teachers use the symbolic level without building connections to the other levels. Linking can occur when teachers instruct at the observable level where students can see, touch or observe a phenomenon, and then move to the molecular level by using the visual representations such as pictures, diagrams or computer animations.

**How Do Students’ Mental Models Change after Using This Approach?**

As to the mental model change, the average percentage results showed many students (57%) had a correct answer after using the molecular level visualisation approach (X/). However, 32% of students still had misconceptions after this approach (XX). The number of students (57%) from the molecular level visualisation approach having incorrect answers in pre-test, and a correct answer in post-test (X/), was higher than the number of students from Class B (27%) (animations with the traditional approach), and was even higher than the Class A students (12%) (traditional approach). In addition, the number of students (73%)
from Class A having incorrect answers in both pre-test and post-test (XX) was higher than the number of students (58%) from Class B, and was higher than those who went through the molecular level visualisation approach in Class C (32%) (see Figure 5.52).

Figure 5.52. Bar chart comparing the three approaches in terms of mental model change before and after learning with each approach

*Note:* // = Correct answer both pre-test and post-test

/X = Correct answer pre-test and incorrect answer post-test

XX = Incorrect answer both pre-test and post-test

X/ = Incorrect answer pre-test and a correct answer post-test

Interview data, coded and analysed using *NVivo*, revealed potential factors which could influence positive or negative mental model change. The analysis was divided into two groups to explore which factors contributed to the results for that group. Group one consisted of students who had misconceptions before and after learning with the molecular level visualisation approach (XX). Group two involved students who improved their understanding after learning with the molecular level visualisation approach (X/) (see Figure 5.53). These two groups were analysed because they consisted of students who each started with misconceptions in the pre-test, and analysis of each group might reveal clues about factors influencing change or lack of change in mental models (see Figure 5.52). The aim of this analysis was to
isolate some of the specific factors that might influence mental model change before and after learning with the molecular level visualisation approach.

Figure 5.53. Factors influencing student mental model change for the two groups as a result of learning with the molecular level visualisation approach

Figure 5.53 shows the factors contributing to the incorrect answers in the pre-test and post-test. Those factors were related in some fashion to (1) the animations (54%), (2) other factors (38%) such as the sound level from speakers, students’ attention, and student ability, and (3) potential issues with the teaching (8%) such as when students complained that the teacher did not explain clearly.

By comparison, factors that lead to a better understanding after the molecular level visualisation approach can be attributed to (1) the animations (76%), (2) the teacher (19%) helping guide the students by explanation and using pictures and diagrams to support the animations, and (3) other factors (5%) such as classmate assistance during the teaching and learning steps.

While animations lead simultaneously to positive and negative results on understanding, this research suggests that it is how the animations are used in the classroom that is significant. With explicit focus on key features, and repeat viewings, or when used as a part of a molecular level visualisation teaching approach, the animations can prove quite effective.
The results overall suggest a positive role for a molecular level visualisation approach. An integrated approach applying a student-centred, constructivist model incorporating animations with other visualisations could help students form better understandings of abstract chemistry concepts. The student interviews suggest that discussing with classmates, or other carefully guided teaching that uses other visualisation techniques like pictures and diagrams could help as well.

Particular conclusions and recommendations are described in Chapter 6.
This chapter presents the discussion and conclusion of the study. First, the purpose and research questions are outlined. Second, the summary results are discussed. Third, theoretical implications of the study, and implications for classroom chemistry teaching, are considered. Finally, I present my recommendations for further research and conclusions about the future of the molecular level visualisation approach in Thailand.

6.1 Purpose of the Study

This study explored the benefits of using a molecular level visualisation approach in Thailand classrooms. In both Phase I and Phase II of the study, and in multiple school and classroom settings, the basic research questions were similar:

1. How do teachers teach when using animations or a molecular level visualisation approach?
2. Do animations or the molecular level visualisation approach help students understand at the molecular level?
3. How do students’ mental models change after learning with animations or the molecular level visualisation approach?

6.2 Summary of the Results

Phase I of the research included three studies. The initial study was a pilot study involving 39 students from the 11th Grade and one chemistry teacher. Drawing tests were given for states of water, and dissolving sodium chloride in water. The drawings tests were used to assess student understanding at the molecular level. Students appeared to have a better understanding, and improved mental models, after learning with animations. However, the results also showed that the teacher and students had misconceptions after using animations.
Study 2 compared two classrooms, one that used animations, and one that did not. Thirty-two students participated in each classroom, and each classroom used the same teacher. The same topics were used as for the pilot study. The results suggested that for states of water, the animation group had a better understanding, whereas for the topic of dissolving sodium chloride in water, the non-animation group appeared to have a better understanding.

Study 3 used an animation for 11th Grade students in three different school areas: a university, a city and a rural school. Eight to thirteen students in each school, and one teacher per school, participated. After learning with an animation on the topic of redox reaction, students in each school had better understandings and improved their mental models. The results were not uniform, however. In particular, students from the university school had better results than for the other schools.

In Phase II, three classes were studied to evaluate the molecular level visualisation approach. Class A used a traditional approach; Class B used the same approach but incorporated animations; Class C used a molecular level visualisation approach. About 40 to 42 students in each class participated, and all were in the 11th Grade. The same teacher was used for Class A, Class B, and Class C. The chemistry topics presented were sodium chloride and ionic precipitation. Data collection techniques included video recordings, a multiple choice test, a calculation test, a drawing test, and interviews. NVivo, paired sample t-test, one-way ANOVA, a conceptual evaluation scheme (applied to the calculation test), and a marking scheme (applied to the drawings) were used to analyse the data. The results suggested that after learning with the molecular level visualisation approach (Class C), students could develop a deeper understanding and improve their mental models better than students in Class A or Class B. However, the results also showed that students still retained misconceptions even after learning with the molecular level visualisation approach.

6.3 Theoretical Implications of the Study

The results from Phases I and II of the study, summarised above, provide support for incorporating animations and using a molecular level visualisation
approach to promote a deeper understanding in chemistry. The molecular level visualisation approach could potentially foster deeper understanding of chemistry concepts among students compared to traditional instruction. Indeed, the molecular level visualisation approach used during Phase II appeared to be more successful in helping students learn than when not using animations (Class A), or when using animations but without a seven-step learning design (Class B).

Notwithstanding the generally positive results resulting from the use of a molecular level visualisation approach, some cautionary points emerged during the course of this research. These points are summarised below:

1. **Persistence of Student Misconceptions**
   
   Although the molecular level visualisation approach showed promise for increasing student understanding, students still had misconceptions. For example, after using animations, some students still believed that a sodium ion and chloride ion are paired together in melted sodium chloride, and many students had misconceptions about chemical formulas and chemical equations.

   The persistence of misconceptions in chemistry is commonly recognised (Chandrasegaran, Treagust, & Mocerino, 2007). Misconceptions can remain even after using well designed animations (Akaygun & Jones, 2013; Kelly & Jones, 2007). If students see something that does not fit their previous conceptions, the students may retain the prior conceptions even after viewing an animation (Kelly & Jones, 2007). Animations therefore play only a part in the teaching process. The animations add a dimension not otherwise available to students revealing, for example, the vibration and movement of atoms, thereby supporting overall student understanding (Vermaat, Krumers-Pals & Schank, 2003), and adding another layer to the overall depth of understanding (Akpinar, 2014).

2. **Teacher Misconceptions**
   
   Phases I and II of this research revealed multiple instances where the teacher appeared to labour under one or more misconceptions. During the Phase I research, the teacher displayed certain misconceptions in the content. For example, the teacher said that a “molecule of water in gas state is very light so it can blow in the air.”
That statement indicated a misconception at the molecular level of water in a gas state. Students, in turn, are likely to have a misconception if the teacher has a misconception. For Phase II, by way of another example, the teacher did not explain how to balance the chemical equation, and students could not solve the problem correctly. Students in the class did not balance the chemical equation before resolving the concentration of the solution.

Why teacher misconceptions existed here is not clear, but could possibly be attributable to using a new approach in the classroom as part of this project. Of course, it could also be the case that the teacher may not have fully understood the topic, and simply misstated certain concepts. If a teacher has a misconception about the content of instruction, then many students in the class will likely develop a misconception too (Kolomuc & Tekin, 2011). It is, after all, the teacher who will present students with learning opportunities in the classroom. Teacher misconceptions in chemistry have recently been documented on a variety of topics (Kolomuc & Tekin, 2011). These teacher misconceptions may be as resistant to change as student misconceptions (Kolomuc & Tekin, 2011).

Research has shown that teacher misconceptions may be passed on to students. Lemma (2013), for example, studied teachers’ and students’ misconceptions about chemistry concepts. Data were gathered from 192 students and six teachers. A multi-tier chemistry misconception test and interview was used to diagnose teachers’ and students’ misconceptions. An 80% to 90% correlation existed between teacher misconceptions and the misconceptions shared by the students.

3. Need for Careful Implementation of Animations

This research confirmed a variety of potential issues that can arise and detract from the learning experience when using animations. Multiple students commented on how fast the animations were presented on screen. The animations were only presented once, and students might find it difficult to fully understand the chemistry concepts based on a single viewing. Audio problems existed in at least one classroom, so the narration of the animation was not clear. The narration was in
English, not in Thai, which could be a challenge for students who are not used to the medium.

In using the animations, the teachers did not uniformly, or consistently, help students to focus on the relevant key features to observe. When teaching with animations, the teacher should consider students’ cognitive load because a large amount of information may be presented all at once, not all of which is relevant to the intended learning objective (Mayer & Moreno, 2003; Sanger, 2009). One of the most useful scaffolding techniques is to narrate an animation while students watch it to direct their attention to the most important aspects (Mayer & Moreno, 2003).

Exactly how the animations are used in the classroom is therefore important, as confirmed by this research project. Prilliman (2014) describes using computer animations, but correctly notes that the students require appropriate guidance from the teacher and practice before they will be able to produce drawings. This research confirms Prilliman’s (2014) observations. Interviews tended to confirm that students would wait for the teacher’s further explanation by static models before the students seemed to understand and put the animation into context, for example.

Other forms of scaffolding that might be considered include the use of static models, or conducting experiments. Recent research confirms the role for static models to complement animations (Al-Balushi & Al-Hajri, 2014). Al-Balushi and Al-Hajri (2014) tested two groups, one that associated animations with static models, and one group that did not. The research pointed out existing studies that suggested a beneficial learning effect when static models and animations were combined. Indeed, the results of the research were that a classroom approach combining concrete models and animations was highly successful.

Laboratory experiments are yet another form of scaffolding that can make the unseen microscopic level more tangible. Using experiments to make a topic more tangible helps students to create links with static models and animations, ultimately helping the students construct better mental models (Akpinar, 2014). In short, animations should be used in conjunction with other kinds of visualisations and
experiments together with guidance from the teacher about what key features to pay attention to.

4. Continued Use of Traditional Instruction in Thailand

Notwithstanding a professed national movement towards a constructivist, student-centred teaching approach, Thailand is still dominated by so-called traditional teaching. This research tended to confirm that the teaching style today remains teacher centred. The teaching is textbook based, with an emphasis on using textbook diagrams, and teachers occasionally will use static diagrams or experiments. Particulate level events in chemistry are largely ignored even though chemistry as a modern science is, to a large degree, about the molecular level (Taber, 2013). Chemistry researchers today seem to agree that student understanding of the particular nature of matter is an essential element of teaching (Dori & Barak, 2000).

5. Student Difficulty Linking to Prior Knowledge

Student difficulty in linking prior knowledge to new knowledge is a theme confirmed throughout this research. Although by Grade 11 Thai students have been taught about chemical substances and balancing equations, the students could not transfer that knowledge to solving the concentration in each ion of solution correctly, or writing chemical formulas correctly. In most instances, the students wrote PCl for the formula of potassium chloride substance instead of (KCl). Dahsah (2007) similarly found that students had misconceptions about the chemical formula. Many students also could not balance the chemical equation correctly. Furi, Azcona and Guisasola (2002) noted student problems with balancing chemical equations.

These common problems were likely the results of inadequate prior knowledge. Before resolving the problem of the concentration in each ion of the solution, for example, students have to understand the chemical formula of substances and how to balance chemical equations. Before teaching and learning in the classroom, the teacher should assess whether students have adequate prior knowledge to study new topics.

If students cannot link prior knowledge to new knowledge, then students may become disengaged, or frustrated, and will not pay attention in the classroom.
Indeed, in many cases during this research, students were observed to show signs of boredom, and were not paying attention during lessons. Those students who admitted not paying attention usually did not understand the topic. Motivation in the classroom (chemistry or otherwise) has been identified as an independent important factor in the success of teaching (Sirhan, 2007). Teachers can have more engaged students by taking the time necessary to gauge the level of class understanding and to prepare students for the new topics, or key features of the new topics, to be presented.

6.4 Implications for Classroom Chemistry Teaching

The results of this research are summarised below in a suggested learning design model that draws on the cumulative research results. In addition, lessons learned from the seven steps of the molecular level visualisation approach are also described.

6.4.1 A Suggested Learning Design Model

The cautionary findings that arose during the course of this research implicate nearly every level of the classroom dynamic: the teacher, the students, the model used, and the instructional methods. Each part of the classroom should be perceived as discrete, important element that impacted the chemistry teaching and learning experience during the course of this research.

Careful review of the data summarised in Chapters 4 and 5 allowed the development of a learning design model (see Figure 6.1). This model was developed, in part, through the highlighting of common issues that appeared either in the videos or in student interviews. For example, students not paying attention was both observed from videos, and self-reported by the students. The teacher presentations revealed multiple apparent instances of misconceptions. During interviews, the students commonly stated that the animations moved too quickly. The test results suggested that a multi-step molecular level visualisation approach involving interactions between students and the teacher, and students with each other, and the careful, applied use of chemistry teaching tools (experiments, models,
animations), could lead to a better understanding. During interviews, students commonly indicated that teacher explanations after the animation helped with understanding. The test data supported a positive learning result from using the animations as part of a process where students observed, drew, discussed with peers, and so on. The learning process was interactive, and interconnected, where each element (teacher, students, classroom tools, learning design) was related to every other element in some fashion. Considering and applying this information, I developed a scheme that, in my view, accurately and succinctly summarised the results of my research.

The model below depicts the interaction between teacher, student and modelling (molecular level visualisations), with Johnstone’s iconic multi-level learning triangle (Johnstone, 2006) at the centre:

![Figure 6.1. Molecular level visualisation approach learning design model](image-url)
The model above depicts a teaching approach unlike the “traditional teaching” discussed in Section 1.1, 1.2, and 1.3.3, and detailed in Section 5.4.1. Students do not only sit passively and listen to teacher lectures, and do not focus only, or primarily, on the symbolic level. Rather, teacher-student interaction is complemented with other important classroom elements such as peer-to-peer interaction, and incorporation of molecular-level animations. The particular steps, and lessons learned in each step, are discussed in more detail in the following section.

The “theoretical implications” discussed in the prior section suggest that nearly every element of the model—teacher, student, animations—influences the success of the teaching in fostering a deep understanding. Having said that, it is difficult accurately to tease apart the importance of any one part of the model relative to other parts on the results discussed in this research. For example, to what degree do prior student conceptions influence the results obtained in this research, compared to language issues with the animation (presentation of an animation in English to Thai students), compared to the influence of peer-to-peer interactions and how those interactions might influence results? At least arguably, simply being aware of these interactions—being conscious of their respective potential impact and importance—has value in how the teaching design is framed and implemented (a sample molecular level lesson plan is contained in Section 6.5).

6.4.2 Lessons Learned from the Seven Steps Molecular Level Visualisation Approach

The molecular level visualisation approach used during Phase II is the mechanism, or tool, by which the various elements in Figure 6.1 are allowed, or enabled, to interact. The approach can be successful when implemented with appropriate forethought. Just as animations cannot necessarily succeed, by themselves, to improve student understanding, so too the molecular visualisation approach requires thought and practice in exactly how it is applied. The discussion below highlights some of the key lessons learned in each of the seven steps.
Step 1: Observing a Phenomenon

Students can observe phenomena directly in class experiments, or from a video. During the course of this research, students conducted experiments in the classroom such as observing salt or dissolved sodium chloride, and for some topics the teacher presented a video in lieu of laboratory work (melted sodium chloride, silver nitrate solution and precipitation).

The use of videos sometimes results from resource issues: the school may not have had enough of a chemical substance, or may have lacked the necessary laboratory equipment. Some experiments can be too dangerous, too expensive, or too time consuming to conduct.

Although laboratory materials may be unavailable, the observation step is important and should be retained in all schools even if only by video. The use of video observations is not necessarily problematic. Lunetta and Hofstein (1991) noted that interacting with instructional simulations can help students understand a real system, process, or phenomenon. They suggested that within school settings, both practical activities and instructional simulations can enable students to confront and resolve problems, to make decisions, and to observe the effects. Certainly, use of video observations of laboratory experiments is preferable to no experiment effort at all.

Of course, where practicable, actual laboratory experiments should be conducted. In-class experiments are important not only for the direct chemistry knowledge, but also for students to obtain an understanding of the science process (Tobin, 1990). In addition, Lazarowitz and Tamir (1994), and Lunetta (1998) suggested that laboratory activities have the potential to enable collaborative social relationships, positive attitudes toward science, and cognitive growth.

Whether by laboratory experiments, or by a video, the observation step helps students to prepare for upcoming topics by allowing the gradual development of ideas—a “careful sequencing” in a “stepwise approach”—that can help prevent working memory overload (Reid, 2008). Observation stimulates students to begin to focus on the topic and reduces the mental load of subsequent activities. This kind of
Step 2: Describing and Drawing a Molecular Level Representation

After students observed a phenomenon, the next step was describing and drawing a molecular level representation to explain the phenomenon. Students have to imagine what is happening at the molecular level during the observation step above (video or class experiments). Up to this point, the students have only made observations with their naked eyes. The picture that students draw at this step of the visualisation process is generated from their imagination combined with the students’ prior knowledge.

The drawings revealed that many students were confused about how to draw the particles at the molecular level. The difficulty drawing particles likely stems, in part, from lack of guidance on drawing at the molecular level. During the drawing process, representations of the building blocks of substances at the molecular level should be provided to students (see Figure 6.2). Providing these building blocks is a part of the process a teacher can use to give the students the necessary visual literacy within which to communicate their further classwork—some of the difficulties students face in chemistry can be tied simply to the “way of talking about it” (Sirhan, 2007, p. 7).

![Figure 6.2. The building block of water molecule](image)

Providing a way to represent the building blocks for students can assist students to draw in the same way. It should be noted, however, that drawing at the
molecular level without providing the building blocks may have the limited advantage of highlighting the unique ideas of individual students.

In this research, the pictures that students drew in this step were ultimately compared to pictures drawn after exposure to modelling of molecular level events (Steps 4 and 5).

**Step 3: Discussing with Peers**

After students prepared drawings at the molecular level, the next step was to discuss these drawings with classroom peers. During this step, students can compare ideas with each other and, in theory, learn something from their fellow students.

Video observations for this research revealed that, for the most part, students were very active and engaged during the peer discussion component. Students have felt that working in groups or pairs was an effective way for them to help each other and to challenge each other (Liu, 2004; Treagust, Chittleborough & Mamiala, 2003). Moreover, Tepsuriyanond (2002) suggested that cooperative learning promotes more active learning, and enhances students’ conceptual understanding.

**Step 4: Viewing a Modelling of Molecular Events**

Students next viewed animations, pictures and diagrams. Many students volunteered during interviews that they had a better understanding after viewing the animations. The test results support the perception of the various students who believed they had a better understanding. Student misconceptions did remain, and the successful use of animations requires careful, guided, pre-animation and post-animation teacher assistance.

During the Phase II research, the video recording showed some potential problems with the teaching, and those problems appear to have resulted in student confusion. The teacher did not appear confident about using the animations. The teacher sometimes called the particles in the animation a sodium ion, and sometimes a chloride ion. The teacher might have been confused about the colour of the particle in the animation (see Figure 6.3). The teacher, while having received some prior
training from me, was also still using a new method, and may simply have felt uncomfortable.

![Figure 6.3. The colour of sodium ions (grey) and chloride ions (green)](image)

As noted above, the animations were in English. Although the students had been learning English for at least ten years, and although the teacher explained the animation in native Thai language, students probably still did not understand the animations. Johnstone and Selepeng (2001) found that second language learners have greater difficulty understanding cognitively-demanding content than learners in a first language setting.

During the implementation of the molecular level visualisation approach, pictures and diagrams were used in addition to animations. Interviews with students whose test results showed a better mental model change said combining pictures and diagrams with animations helped. As already noted above, research completed in 2014 confirms an important role for static visualisations in chemistry teaching.

Visual representations can encompass a broad range of objects, such as computer animations, diagrams, pictures, and ball and stick models (Vavra et al., 2011). Tepsuriyanond (2002) found that using a variety of learning material promotes more active learning and enhances students’ conceptual understanding. In addition, Bucat (2004, p. 223) observed that sometimes a teacher will need to point out the general behaviour of particles, and other times may need to focus on a single particle for a particular purpose. Single particle representations are not adequate to teach boiling, or dissolving, for example. The appropriate tool must be chosen for the desired teaching outcome.
Step 5: Reflecting on Differences

After viewing animations, pictures and diagrams in Step 4, students had to make another drawing and compare this drawing to prior drawings from Step 2. Students are thus invited to reflect on any difference between new and prior conceptions.

The drawing results suggested that a majority of students had a better understanding after viewing the animations, pictures and diagrams in Step 4. The percentage of students who had correct answers or developed a better understanding, after the visualisation approach was higher than for the other categories of students (i.e., those with students no mental model change or who went from correct to incorrect) (see Table 5.9 comparing average percentage result). These results were confirmed in student interviews, where students believed they had a better understanding after viewing visualisation and modellings, and after additional teacher explanations. Factors at play for varying student test results include different student abilities and different prior knowledge. Dahsah (2007) recommended for topics like solving numeric problems that teachers spend the time necessary to consider the students’ prior knowledge.

The test results during Step 5 of this research were divided into four groups depending on how students answered before and after viewing visualisations (see Table 5.9). The two smallest groups were those where the students gave correct answers both before and after the visualisations, or where the initial answers were correct but then were changed to be incorrect. Thus, most of the answers were incorrect before viewing the visualisations. Students seemed to have a hard time drawing the particles at the molecular level correctly before a viewing (indicating low prior knowledge) because students were not familiar with how to make representations at the molecular level. Student interviews showed that misconceptions may relate to the complexity of the animations, the speed of the animations, the teacher’s explanation, or the ability of the particular student (see Figure 5.53). The largest group on a percentage basis—as noted above—was the group that displayed a better understanding after viewing the visualisations (those coded as “X”). Fifty-seven percent of students displayed a better understanding after the visualisation approach, compared to 32% of students who were incorrect in
the before and after state, 8% that were correct both in the before and after state, and 3% of students who went from correct to incorrect answers. The improvement in understanding suggests a place for the molecular level visualisation approach in the teaching process, but as noted above, requires accurate teacher guidance, and may be influenced by student ability, student prior knowledge, and the kind(s) of modelling/visualisations presented.

**Step 6: Expressing Ideas Using Symbols or Scientific Terms**

The sixth step of the molecular level visualisation approach was expressing the ideas using symbols and scientific terms, and linking the three levels together.

The findings from this study indicated that teaching and learning that links the three levels of thinking together could foster deep understanding, and the results showed improvement over the traditional approach. The traditional approach did not link the three levels together, and students from the traditional approach did not make molecular level drawings before and after viewing the visualisation and modelling (if any).

As developed in more depth in Chapter Two, research studies have generally confirmed the effectiveness of chemistry learning in three levels. For example, Jansoon et al. (2009) observed that students who understand the role of the three levels can transfer knowledge from one level to another, and can generate relational understanding. On the other hand, student difficulty in learning chemistry could be due to a lack of understanding of the relationships between the levels (Johnstone, 1993).

Teaching by linking all three levels together is difficult (Nakhleh, 1992 & Johnstone, 1993). Indeed, using a three levels of thinking analysis requires, to some extent, a shift in the basic traditional approach teaching paradigm. To get that shift in paradigm may require presentations to teachers and school administrators in Thailand, and is one of the further recommendations below.
Step 7: Transferring Ideas to New Situations

The last step was to transfer ideas to new situations. Students could be asked to use their mental model to explain another new phenomenon. The teacher could inquire, for example, if the temperature increases, how do the particles change in salt, and why? Or if we change the salt to be sugar in water, the arrangement of the particles in sugar is similar to salt, or different, and why?

The video recordings showed a problem implementing this step. The teacher did not uniformly ask questions of the students requiring a transfer of ideas to new situations or, if she did, did so without developing the discussion. For example, when teaching the topic of sodium chloride in a solid state, the teacher did not use Step 7 to apply the knowledge to new situations. The reason for this step being left off is unclear, although it is generally hard to take classroom lessons and then apply them to new situations with the students. As revealed during the transfer test for calculations, students frequently had trouble applying their knowledge to new situations. For example, when the chemical substance was changed to be magnesium chloride, students could not draw the arrangement of the particles in MgCl₂ correctly. Kent (1990) and Peters (2003) stated that higher order thinking processes to transfer to new situations are very difficult to teach and to learn.

Overall, this Step 7 might be a limitation on this research as its effect on the results cannot accurately be measured. More focus on this step would likely require a significant effort by the teacher to think not only about the lesson plan, but then also to think about one or more extensions of the lesson plan to new scenarios that could aid in student understanding. Additional focus on this step in the future is recommended.

6.5 Sample molecular level visualisation approach lesson plan for Thai classroom chemistry teaching--dissolving sodium chloride in water

The following provides a concrete example of a lesson plan which could be implemented by a Thai secondary school chemistry teacher. Consideration is given to potential resource limitations and likely available equipment or materials. The following describes how the teaching should occur, with justifications drawn
primarily from the data obtained in this research from observation and structured interviews.

A presumption of the following syllabus is that the students have had necessary prior teaching to prepare them for the following topic. For example, prior reading and teaching is presumed to have occurred on the topics of molecular substance, ionic substance, chemical formula and chemical equation.

**Topic:** Dissolving sodium chloride in water  
**Times:** 90 minutes  
**Students:** 40 students will be divided into 5-6 student groups  
**Teacher:** 1 chemistry teacher  
**Equipment/Materials:**  
1. Sodium chloride  
2. Water  
3. Beaker or test tube  
4. Stirring rod  

**Aims of the Study:**  
1. Students understand the arrangement of the particles in sodium chloride solution.  
2. Students are able to link the three levels of thinking.  
3. Students are able to compare drawings from before and after viewing the animations.  
4. Students are able to calculate the concentration of each ion in sodium chloride solution.

**Principle Concepts**  
In sodium chloride solution, sodium ions and chloride ions are separated from each other, and each ion is surrounded by water molecules. The oxygen atoms in water molecules face towards the sodium ions, and the hydrogen atoms in water molecules face towards the chloride ions in sodium chloride solution.
Prompt Students for Interest—10 minutes

Teaching should begin by asking students question to generate interest, prompting students to access prior knowledge, and setting student focus for the instruction. Sample questions could include, for example: “What does solution mean?” or “What is the difference between solution and pure substance?” or “Do you remember the chemical formula for water, or the chemical formula for sodium chloride?”

During this phase, the teacher can gauge student knowledge level, and whether the students need some more background in order to understand the upcoming topic. Certain common misconceptions might come to light during this time. For example, students may not be able to write the chemical formula for water or sodium chloride. If gaps in knowledge, appear, the teacher should provide necessary background such as explaining the chemical formulas.

After a few minutes of general discussion, the teacher should engage the students directly on the topic of sodium chloride solution. For example, “Today, we will study a substance that we commonly experience in everyday life: salt. We will then mix salt with another common substance, water. This is sodium chloride solution, and we will observe what happens when salt and water are mixed, and we will learn about what happens at the molecular level.”

This advance discussion phase helps mentally prepare the students. Proper advance mental preparation will help the students to learn about, and concentrate on, the topic. The advance preparation and discussion phase should last about 10 minutes before beginning the seven steps of the molecular level visualisation approach.

Molecular Level Visualisation Approach:

After the preliminary discussions above introducing the students to the topic, the teacher will begin the seven steps of the molecular level visualisation approach. Students should be divided into groups of about six students per group. The peer to peer discussions in the small group learning environment received consistently good
feedback from students during this research. Recent work in this area supports the value of peer to peer interaction when combined with instructor explanation (Smith, Wood, Krauter & Knight, 2011).

*Step 1: Observing a Phenomenon*—10 minutes

Students in each group will get the same chemicals (water and salt) and apparatus (beaker or test tube and stirring rod). The teacher will ask students to observe the physical properties of salt and water. The teacher will then ask the students to combine salt and water, and to observe the properties of sodium chloride solution.

Observation may take several forms. Students can observe a phenomenon by such methods as in-class experiments, or from a video (see Figure 6.4). If the teacher has a video, the video can be shown before or after observing the in–class experiment. Practical activities such as laboratory work, and instructional simulations, can both enable students to confront and resolve problems, to make decisions, and to observe the effects.

As observation occurs, students should write a list of the physical properties they observed on a paper worksheet (see Table 6.1). During this research, students that noted or recorded the details of their observations were more confident and better able to recall and recite what they learned from the observation. When we ask students to explain the details of their observations after salt is added to water, we expect something like the following: “Salt dissolves to be sodium chloride solution, and it takes around one minute until the salt is finished dissolving. The color of water is more clear than the color of the sodium chloride solution.” The goal is for the students to be able to recall as many of the physical properties as possible with reference to their worksheet.
Table 6.1

*Example of the paper worksheet that the teacher should provide to students to record physical properties observed.*

<table>
<thead>
<tr>
<th>Substances</th>
<th>Physical Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Water</td>
<td></td>
</tr>
<tr>
<td>2. Salt</td>
<td></td>
</tr>
<tr>
<td>3. Sodium chloride solution</td>
<td></td>
</tr>
</tbody>
</table>

After adding salt into water, the teacher should continue to interact with students, and try to activate students’ prior knowledge and help students to think more deeply. This can be done by asking questions that should already be within the students’ existing knowledge, such as: “In everyday life, what kinds of things to you use salt for?” or “In sodium chloride solution, can you still see salt? If not, where is the salt in the solution?” During this research, students responded with answers such as: “We use salt for cooking,” or “We cannot see salt in the solution,” or “The salt changed to be a liquid” or “The salt changed to become water.” Some students responded that they believed salt to be a pure substance. Before moving to Step 2, the teacher has to explain to students that liquid can be solution or pure substance. Sodium chloride solution is a solution where salt is the solute and water is the solvent—it is not a pure substance.

*Figure 6.4. Sodium chloride dissolving at the observable level*

**Step 2: Describing and Drawing a Molecular Level Representation**—10 minutes

After students observe the physical properties of salt, water, and sodium chloride solution in Step 1, the teacher should ask students to imagine the
The phenomenon of sodium chloride solution at the molecular level. The teacher might inquire, for example: “If you look at sodium chloride solution, can you see the particles in the solution? What do you think the arrangement of the particles is in the solution?” Students should then draw and describe the arrangement of the particles of sodium chloride solution (see Figure 6.5). Students will later compare this initial drawing to their new conceptions after the animation viewing in Step 5.

Before  

After

Figure 6.5. An example of a student’s drawing the arrangement of sodium chloride solution between before viewing the animations (Step 2) and after viewing the animations (Step 5)

The students’ drawings and descriptions reflect their prior knowledge. During this research, it was common to find that students felt confused when the teacher asked them to draw and explain sodium chloride solution at the molecular level. However, students were less confused if the teacher provided the building block of sodium ion, chloride ion and water molecules to students (see Figure 6.6). The building blocks provided a “common language” to help students draw the particles of sodium chloride solution in the same way, and made it easier to compare the change in knowledge between Step 2 (molecular arrangement drawn from the imagination) and Step 5 (molecular arrangement drawn after viewing animation).
**Step 3: Discussing with Peers—10 minutes**

As noted above, the peer to peer dynamic has received positive feedback from students, and seems generally supported by existing research. Step 3 is set aside to encourage this kind of active learning between the students with a minimum of teacher guidance.

During Step 3, students will discuss their Step 2 drawings and descriptions with peers in one-on-one discussions within the individual groups. Students should write their notes during this step to a paper worksheet (see Figure 6.7). In particular students should document similarities or differences between their drawings and descriptions with those of their peers.

With reference to your Step 2 drawings, describe common features of your drawing with your classmates.

Now, after you have discussed common features (if any), discuss differences between your drawing and that of your classmates. Explain at least one difference you had with your classmate………………………………………………………………

**Figure 6.6.** The building block of sodium ion and chloride ion

**Figure 6.7.** An example of a paper worksheet for peer-to-peer discussions
During this time, the teacher should be walking around the classroom and randomly observing drawings and explanations. However, the teacher should not make corrections but, rather, allow the students to engage in discussion about the similarities or differences that their drawings or explanations might have with peers. Students will be able to proof their own diagrams and descriptions after viewing the animation, picture and diagram, and after discussing with the teacher in Step 4.

**Step 4: Viewing a Modelling of Molecular Events—15 minutes**

During Step 4, the students will be presented with an animation of the phenomenon of sodium chloride solution. Combining animation with lab work will enable students to better conceptualize the workings of particles at the molecular level (Velazquez-Mercano, Williamson, Ashkenazi, Tasker & Williamson, 2004). The animation should be viewed three times. Multiple viewings are advisable because a common complaint of students was that the animations were too fast (and the animation was in English).

Prior to the first viewing, the teacher should help prepare students mentally by identifying key features to look for (Kelly & Jones, 2007).

The first viewing of the animation will be without stops. Because the animation is in English, guidance from the teacher during or after the animation is advisable.

The second viewing of the animation will incorporate stops on particular frames to isolate and discuss key features. Incorporating stops—pause points—has been demonstrated to be important for promoting student reflection (Kelly & Jones, 2007). For example, the teacher should stop the animation on the frame below for the purpose of describing that the sodium ion and chloride ion are separated from each other and surrounded by water molecules (see Figure 6.8).
The teacher should again stop on the frame below. The frame below is useful for highlighting and explaining that the oxygen atoms in water molecules face towards the sodium ions, and that the hydrogen atoms in water molecules face towards the chloride ions in sodium chloride solution (see Figure 6.9).

**Figure 6.8.** The arrangement of sodium chloride solution

**Figure 6.9.** The arrangement of sodium ion and chloride ion

During the pauses in the animation, the teacher should ask students to note the key feature of the phenomenon of sodium chloride solution to a paper worksheet (see Figure 6.10). As noted above, when students document their observations, they are generally better able to recall the information.

Again during the pauses, the teacher should ask questions to check student understanding. The teacher might ask, for example, which water molecule faces towards the sodium ion. If students cannot give a correct answer, then the teacher
has to explain again by using animation or a diagram from the text book, or drawing the particles of solution on the whiteboard.

<table>
<thead>
<tr>
<th>Notes from viewing the animation, picture and diagram.</th>
</tr>
</thead>
<tbody>
<tr>
<td>........................................................................</td>
</tr>
<tr>
<td>........................................................................</td>
</tr>
<tr>
<td>........................................................................</td>
</tr>
</tbody>
</table>

*Figure 6.10. An example of paper worksheet to record from viewing the animation, picture and diagram*

After viewing the animation the second time (with appropriate pauses to explain key features), the teacher should use the diagram of sodium chloride solution from the Thai chemistry text book (see Figure 5.1), and then draw the picture of the arrangement of the particles in solution on the whiteboard to support the key feature from the animation.

Finally, a third viewing is advisable to cement the preceding discussion and to act as an additional scaffold or support to the observations and discussions occurring during viewing number one and viewing number two. Multiple presentations is consistent with student observations that the animations were too fast, and helps account for language differences and the students’ ability to process. In general, multiple opportunities to view molecular level events is an instance of slowing—making the teaching less speedy—so as to reduce the load on working memory (Reid, 2008).

*Step 5: Reflecting on Differences*—10 minutes

Student will draw and describe the phenomenon of sodium chloride solution again after having viewed the animation, textbook diagram and teacher provided picture during Step 4. Students’ drawings and descriptions can then be compared to the phenomenon of sodium chloride solution from Step 2 (see Figure 6.5). Research has confirmed that the process of reflection is more effective than the teacher simply listing and discussing common misconceptions (Tasker & Dalton, 2006).
This research also confirms a positive role for reflection. Time set aside where students must focus attention on their notes appears to have led to better understanding. While the focus of Step 5 should be on student reflection, some preparation for “linking” to the symbolic level in Step 6 needs to occur, and the teacher should explain each key feature of the phenomenon of sodium chloride solution to students in the class. Even if not the focus of this step, some class discussion directed by the teacher at possible misconception points has been identified as valuable when using animations (Kelly & Jones, 2007).

**Step 6: Expressing Ideas Using Symbols or Scientific Terms to Relate to Other Thinking Levels**—15 minutes

The goal of Step 6 is to link knowledge gained from the laboratory (observable) and from the animation (molecular) to the symbolic level. The process of linking is a foundational concept generally accepted to be important to student understanding of chemistry (see Section 2.1).

The teacher should activate students by asking them to write a chemical equation of sodium chloride solution in the paper worksheet (see Figure 6.11).

Write the chemical equation of sodium chloride solution.

...........................................................................................................................................................

**Figure 6.11.** An example of a paper worksheet to write the chemical equation of sodium chloride solution

After the students write the chemical equation, then the teacher should explain the correct chemical equation of sodium chloride solution to students (see Figure 6.12).

\[
\text{NaCl(s)} + \text{H}_2\text{O(l)} \rightarrow \text{Na}^+(aq) + \text{Cl}^-(aq)
\]

S = solid
l = liquid
aq = aqueous

**Figure 6.12.** The correct chemical equation of sodium chloride solution
The teacher should continue to prompt students by asking some questions to probe the level of student understanding. For example, “What is the difference between Na and Na⁺?” During this research, many students did not understand the difference between Na and Na⁺. The teacher should also ask students about the state of substances. For example, “Do you know what ‘aq’ means?” The teacher should be asking questions with the goal of linking to students’ prior knowledge. A key concept during this phase is for students to understand that the sodium ion Na⁺ (aq) is surrounded by water molecules.

For the linking of the symbolic level to the other levels, a diagram might be considered such as the one below in Figure 6.13.

![Summary](image)

*Figure 6.13. Three levels thinking of sodium chloride solution*

The end goal of this step is that the student will be able to link from their initial observations of salt, water and sodium chloride solution (Step 1), to the molecular level events revealed during Step 4, and then ultimately to the symbolic level in Step 6.

**Step 7: Transferring Ideas to New Situations or New Topics**—10 minutes

Effective use of visualisation requires encouraging students to apply their skills to new situations, and ultimately to assess their knowledge (Tasker & Dalton, 2006). The teacher should ask students to transfer their knowledge to new situations or new topics. The teacher, could, for example, ask students to calculate the
concentration in each ion and draw the arrangement of another ionic solution and write the chemical equation. For example, calcium chloride solution; CaCl$_2$(s) + H$_2$O(l) $\rightarrow$ Ca$^{2+}$(aq) + 2Cl$^-$ (aq). The ratio of this calcium chloride solution between Ca$^{2+}$: Cl$^-$ is 1:2. To reach the correct conclusion, the student has to be careful about balancing the equation before calculating the concentration of the calcium ion and the chloride ion. The teacher should explain about how to write and balance the chemical equation clearly with consideration of the students’ prior knowledge of chemical formulas (we found during this research that many students could not write the chemical formulas correctly—see Section 5.3.2.1).

6.6 Recommendations

During the course of this research, potential problems were discovered with the national Thai chemistry textbook. Additional research about the reason or reasons for differences in the results between university, city and rural schools could also be undertaken.

6.6.1 Recommendation for Modifications to the Thai Chemistry Textbook

In Thailand, most secondary schools use a chemistry textbook from the Institute for the Promotion of Teaching Science and Technology [IPST]. The pictures and diagrams in the Thai chemistry textbook are often used as static examples to teach students. In several instances, the diagrams in the textbook might have contributed to student misconceptions. For example, the diagram of dissolving sodium chloride in water showed only one sodium ion and one chloride ion surrounded by water molecules (Institute for the Promotion of Teaching Science and Technology [IPST], 2010, p.119). In fact, there are many sodium and chloride ions in the solution. Students could develop immediate misconceptions about the number of particles in the solution. Moreover, a misconception about the arrangement of substances in a solid state was also found in the Thai chemistry textbook (see Figure 6.14—the Thai writing is translated as “the arrangement of particles in a solid state”).
Figure 6.14. The arrangement of particles in a solid state (Institute for the Promotion of Teaching Science and Technology [IPST], 2011, p.103).

Figure 6.14 showed the arrangement of particles in a solid state using ice (water in a solid state) as the example. Contrary to what the diagram indicates, the arrangement of the particles of ice (water in a solid state) is different than other substance in a solid state. The particles of ice or water in a solid state are arranged neatly, and there are spaces between the particles (see Figure 6.15). The spaces are not evident or showing in the textbook example.

Figure 6.15. The arrangement of water in a solid state as depicted in a VisChem animation

Figure 6.15 accurately shows the arrangement of water in a solid state where spaces exist between molecules of water. The textbook diagram in Figure 6.14, by contrast, could lead to misconceptions about the arrangement of water in a solid state. Indeed, students from Phase I, Study 1, often observed that “molecules of ice are close together.” Students were asked “Does ice float in water?” and students
would often respond: “Yes, it does.” To answer whether ice can float in water, a student would have to understand that the ice can float in water because empty spaces exist between the molecules of water. The empty spaces make the volume of the ice greater than the volume of water in a liquid state. Without a clear and correct visual representation, students might not be able to answer or provide an adequate justification for the answer.

The results from Phase I, Study 2, also tended to confirm a potential problem with the textbook. On the topic of the lattice structure of ice (arranged neatly and spaced), the score from the animation group (56.63%) was higher than for the non-animation group (0%). The non-animation group used only the textbook diagram from the chemistry textbook to learn that topic, thus suggesting a possible link between the textbook diagram and the relatively poor scores.

6.6.2 Recommendation for Further Research

Workshops in Thailand to promote a molecular level visualisation approach could be useful. Workshops could heighten awareness about teaching options, could place more emphasis on the three thinking levels, and could promote the use of animations. The workshops could perhaps capture the attention of school administrators, and at the same time give teachers the confidence to explore a new approach.

Possible further research could be conducted using some of the methods in this research. A broader sample of students, and using different topics, could lead to further insights about how best to use a visualisation design approach and animations. One interesting aspect of future research could be to focus on the particular kinds or types of misconceptions before and after viewing animations. This research, for example, did not specifically catalogue how many types of misconceptions existed before and after using animations, or before and after completing the visualisation approach teaching steps. In addition, further developing the data from rural, city and university schools should be considered by considering the background of students’ families, socio-economic status, and so on. The rural school used in Phase I had only eight students, and a larger pool would provide more
meaningful data. The more details that are gathered, the more likely that accurate conclusions can be drawn about reasons for differences in the test results between the schools.

6.7 Conclusion

This research confirms a potential long term role for a molecular level visualisation approach in Thailand. For too long, teaching has largely ignored the molecular level. There is no good reason to ignore molecular level reactions in chemistry. Indeed, failure to do so would seem to be contrary to generally accepted chemistry teaching practices today. The results of this research suggest that student understanding of chemistry level molecular reactions does indeed improve by and through the use of a molecular level visualisation approach.

Chemistry education in Thailand usually has a result oriented goal: pass university entrance examinations. That narrow goal does not necessarily lead to well informed students who can take and apply their knowledge outside the classroom, and in contexts other than examinations. This research confirms that a carefully implemented, multi-step, molecular level visualisation approach can succeed in Thailand. The administrators and teachers I spoke to during the course of this research were enthusiastic about this research project, and about exploring ways to improve chemistry teaching.

The learning design I have suggested is interactive, and dynamic. Every part of the design relates to every other part in some fashion. However, the results of this research suggest that perhaps the most dramatic shifts in teaching in Thailand could result from focus on the molecular-level, multi-step visualisation approach, and by paying more attention to teaching tools like animations. By making the molecular level an explicit part of chemistry teaching as a part of a broader learning design, it is my belief that Thailand can see positive, long term improvement in student chemistry understanding.
REFERENCES


Nakiboglu, C. (2003). Instructional misconception of Turkish prospective chemistry teachers about atomic orbital and hybridization. *Chemistry Education Research and Practice, 4*, 171-188


Taber, K. S. (2013). Revisiting the chemistry triplet: Drawing upon the nature of chemical knowledge and the psychology of learning to inform chemistry education. *Chemistry Education Research and Practice, 14*, 156-168.


APPENDICES
APPENDIX A

Human Ethics Approval
UWS HUMAN RESEARCH ETHICS COMMITTEE

10 May 2012

Associate Professor Roy Tasker,
School of Science and Health

Dear Roy,

I wish to formally advise you that the Human Research Ethics Committee has approved your research proposal H9505 "Implementation of the Molecular-Level Visualisation Approach in Chemistry Teaching in Thailand", until 15 April 2014 with the provision of a progress report annually and a final report on completion.

Please quote the project number and title as indicated above on all correspondence related to this project.

This protocol covers the following researchers: Chatree Faikhamta, Robyn Gregson, Roy Tasker, Butsari Phenglengdi.

Yours sincerely

Dr Anne Abraham
Chair, UWS Human Research Ethics Committee
APPENDIX B

Consent Forms
Participant Consent Form

This is a project specific consent form. It restricts the use of the data collected to the named project by the named investigators.

Note: If not all of the text in the row is visible please ‘click your cursor’ anywhere on the page to expand the row. To view guidance on what is required in each section ‘hover your cursor’ over the bold text.

Project Title: Implementation of the Molecular-Level Visualisation Approach in Chemistry Teaching in Thailand

I, ___________________________, consent to participate in the research project titled Implementation of the Molecular-Level Visualisation Approach in Chemistry Teaching in Thailand.

I acknowledge that:

I have read the participant information sheet [or where appropriate, ‘have had read to me’] and have been given the opportunity to discuss the information and my involvement in the project with the researcher/s.

The procedures required for the project and the time involved have been explained to me, and any questions I have about the project have been answered to my satisfaction.

I consent to the:
( ) videotaping of classroom instruction or interviews;
( ) audiotape recording of classroom instruction or interviews;
( ) photos of classroom instruction or interviews;
( ) face to face interview (select student volunteers);
( ) class attendance;
( ) participation in a pre-test, post test, test of logical thinking and attitude questionnaire.

Please cross activities that you wish to participate in.

I understand that my involvement is confidential and that the information gained during the study may be published but no information about me will be used in any way that reveals my identity.

I understand that I can withdraw from the study at any time, without affecting my relationship with the researcher/s now or in the future.

Signed: ________________________________

Name: ________________________________

Date: ________________________________

Return Address: Butsari Phenglengdi, K8Room 32Hawkesbury campus, Locked bag 1797, Penrith NSW 2751

This study has been approved by the University of Western Sydney Human Research Ethics Committee. The Approval number is: [enter approval number]
If you have any complaints or reservations about the ethical conduct of this research, you may contact the Ethics Committee through the Office of Research Services on Tel +61 2 4736 0229 Fax +61 2 4736 0013 or email humanethics@uws.edu.au. Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.
Participant Consent Form for Parents/Caregivers

This is a project specific consent form. It restricts the use of the data collected to the named project by the named investigators. Where projects involve young people capable of consenting, a separate consent form should be developed. A parental consent form is still required.

Note: If not all of the text in the row is visible please 'click your cursor' anywhere on the page to expand the row. To view guidance on what is required in each section 'hover your cursor' over the bold text.

Project Title: Implementation of the Molecular-Level Visualisation Approach in Chemistry Teaching in Thailand

I, [print name] .................................., give consent for my child [print name] ........................................to participate in the research project titled Implementation of the Molecular-Level Visualisation Approach in Chemistry Teaching in Thailand.

I acknowledge that:

I have read the participant information sheet [or where appropriate, 'have had read to me'] and have been given the opportunity to discuss the information and my child's involvement in the project with the researcher/s.

The procedures required for the project and the time involved have been explained to me, and any questions I have about the project have been answered to my satisfaction.

I have discussed participation in the project with my child and my child agrees to their participation in the project.

I understand that my child's involvement is confidential and that the information gained during the study may be published but no information about my child will be used in any way that reveals my child's identity.

I understand that my child's participation in this project is voluntary. I can withdraw my child from the study at any time, without affecting their academic standing or relationship with the school and they are free to withdraw their participation at any time.

I consent to the

( ) videotaping of classroom instruction or interviews;
( ) audiotape recording of classroom instruction or interviews;
( ) photos of classroom instruction or interviews;
( ) face to face interview (select student volunteers);
( ) class attendance;
( ) participation in a pre-test, post test, test of logical thinking and attitude questionnaire.

Please cross out any activity that you do not wish your child to participate in.

Signed (Parent/caregiver): ___________________________ Signed (child): ___________________________

Name: ___________________________ Name: ___________________________
Where projects involve young people capable of consenting, a separate consent form should be developed. A parental consent form is still required.

Return Address:  
Butsari Phenglengdi, K8 room 32 Hawkesbury campus, Locked bag 1797 Penrith NSW 2751

This study has been approved by the University of Western Sydney Human Research Ethics Committee. The Approval number is: [enter approval number]

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APPENDIX C
Multiple Choice Test
Multiple Choice Test

Directions:
1. This test is a multiple choice test
2. There are 10 questions
3. Choose only 1 answer
4. You have 30 minutes to complete this test

1. The diagram below represents a mixture of S atoms and O$_2$ molecules in a closed container:

![Diagram of S and O$_2$ molecules]

Which option represents the contents of the container after the original mixture reacts as completely as possible according to the equation:

$$2S + 3O_2 \rightarrow 2SO_3$$

Key

![Key with S atom and O$_2$ molecule icons]

(A)  
(B)  
(C)  
(D)  
(E)
2. Dilute solutions of potassium nitrate (KNO$_3$) and sodium sulfate (Na$_2$SO$_4$) are mixed together. There is no precipitate. The magnification diagram shows a view of a small portion of this solution.

Which option best represents the chemical species that are present in solution?

Key

(A)  
(B)  
(C)  
(D)  
(E)
APPENDIX D
Calculation Test
The Calculation Test

Directions:
1. There are 3 questions, and each question has 2 sub-questions including (a) to calculate the concentration and (b) to draw the particles at the molecular level.
2. Use the keys below to draw in each question.
3. 50 minutes for this test.

Key:

\[
\begin{align*}
\text{K}^+ &= \bullet \\
\text{Cl}^- &= \circ \\
\text{Mg}^{2+} &= \circ \\
\text{H}_2\text{O} &= \text{H}_2\text{O}
\end{align*}
\]

Question 1. In a 0.5 mol/L KCl solution
(a) Calculate the concentration of K\(^+\) and Cl\(^-\) ions.
(b) Draw the particles in the KCl solution to include water molecules at the molecular level.

Question 2. In a 0.5 mol/L MgCl\(_2\) solution
(a) Calculate the concentration of Mg\(^{2+}\) and Cl\(^-\) ions
(b) Draw the particles in the MgCl\(_2\) solution to include water molecules at the molecular level

Question 3. 50 mL 0.2 mol/L KCl is added to 100 mL 0.1 mol/L MgCl\(_2\)
(a) Calculate the total concentration of Cl\(^-\) ions after mixing the substances.
(b) Draw the correct ratio of particles in the mixed solutions of KCl and MgCl\(_2\) to include water molecules at the molecular level.
APPENDIX E
Drawing Test
**Drawing Test for Phase II**

**Directions:**
1. Draw and explain the arrangement of the particles at the molecular level for each of the five topics.
2. When making your drawings, use the key symbols as displayed below.
3. You will have a total of 50 minutes to complete this test.

**Keys:**

<table>
<thead>
<tr>
<th>Topic</th>
<th>Molecular level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Drawing</td>
</tr>
<tr>
<td>1. Solid NaCl</td>
<td></td>
</tr>
<tr>
<td>2. Melted NaCl</td>
<td></td>
</tr>
<tr>
<td>Topic</td>
<td>Molecular level</td>
</tr>
<tr>
<td>-------</td>
<td>----------------</td>
</tr>
<tr>
<td></td>
<td>Drawing</td>
</tr>
<tr>
<td>3. NaCl solution</td>
<td></td>
</tr>
<tr>
<td>4. AgNO₃ solution</td>
<td></td>
</tr>
<tr>
<td>5. AgCl precipitation (mixed NaCl+AgNO₃ solutions)</td>
<td></td>
</tr>
</tbody>
</table>

Please draw all particles in the mixed solution
1. If you see water in a beaker, what do you imagine the molecules of water look like? Draw a molecule of water, and then draw water molecules in a liquid state.

2. For molecules of water in a liquid state, do the molecules collide and move, how?

3. Draw water molecules in a solid state. Can molecules of water in a solid state vibrate in a fixed position? Does any space exist between the molecules?

4. Draw the particles in melted sodium chloride?

5. Draw the particles in sodium chloride solution?
**Drawing Test for Phase I (Study 2)**

*States of Water and Sodium Chloride*

1. If you see water in a beaker, what do you imagine the molecules of water look like? Draw a molecule of water, and then draw water molecules in a liquid state.

2. For molecules of water in a liquid state, do the molecules collide and move, how?

3. Draw water molecules in a solid state. Can molecules of water in a solid state vibrate in a fixed position? Does any space exist between the molecules?

4. Draw the particles of sodium chloride in a solid state?

5. Draw the particles in melted sodium chloride?

6. Draw the particles in sodium chloride solution?
Drawing Test for Phase I (Study 3)
The Redox Reaction

1. Draw and explain the particles in copper metal?

2. Draw and explain the particles in a silver nitrate solution?

3. After placing copper metal into silver nitrate solution, draw and explain about how copper metal loses electrons and how silver ions gain electrons?
APPENDIX F
Interview Protocol
**Semi-Structured Interview Protocol**

The following questions will be posed to students:

1. Do you think differently about chemistry or the specific topics we talked about after learning with animations? How?

2. Do you think that animations help you better understand at the molecular level? How? Which part of the animations helps or doesn’t help? Why?

   Do you remember?

3. Does the teacher help you understand at the molecular level? How?

4. Do your classmates or friends help you more understand at the molecular level? How?

5. What is your opinion of this type of teaching?