Student-generated animations and the teaching and learning of chemistry

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature: Date:

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Dedication

This thesis is dedicated to:

My supportive husband, Muhammad Yaseen, who has provided me with love and endless support, and to my son Arqam. Without my husband's support this research would not have been possible.

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Abstract

This study investigates the use of student-generated animations in the teaching and learning of chemistry. Previous research has identified the potential for animations to contribute to student learning in science. In particular, animations have the capacity to represent the dynamic processes and motions that may be inherent in some chemical concepts. This study focuses on animations that students produced with the support of their teacher and their fellow students. The literature review brings ideas together from social constructivism, representational pedagogy and analogical reasoning to highlight the implications of this research.

The research investigated a teaching intervention that was designed to investigate the following conjecture: That students working in groups to create their own animations to represent their conceptions, when supported by their teacher to analyse the animations in group discussions, develop their understanding of science concepts.

The participants in the study were 28 Year 11 Science students and their science teacher. The concept the students were learning was states of matter. The teaching intervention included training the students in the use of animation software, followed by the students working in pairs or groups of three to create animations representing their conceptions of solid, liquid and gaseous states of matter. Students were supported by their teacher and encouraged to discuss ideas as they constructed their animations. After completion of the animations, the teacher facilitated the students to analyse and discuss their own animations as well as animations that had been produced by experts. Data collection included pre- and post-tests, classroom observation, videorecording of lessons, collection of artefacts (the students' animations) and interviews with the teacher and students.

Use of the student-generated animations created an opportunity to represent and discuss conceptions of the states of matters, including dynamic elements of their conceptualisations. The teacher's scaffolding of the groups during their animating, helped them to accurately represent their conceptions. The teacher became aware of her students' misconceptions and otherwise hidden understandings as they created their animations. In their analysis of the various animations, students identified differences and similarities among their animations. As well, by comparing attributes of their conceptions of states of matter with attributes shown in their animations, they identified those that were matching and mismatching. They also critiqued expert animations of states of matter. Data from pre/post-tests, observations and interviews indicate that the students improved their understanding of states of matter through the teaching/learning process that occurred during the intervention.

Chapter 1: Introduction to the Thesis

1.1. Introduction to the chapter

Science educators often use animations to support students' learning, but there is little research on the contribution to learning of students creating their own animations (Chang & Quintana 2006; Hoban, Macdonald, Ferry & Hoban. 2009; Hoban & Nielsen 2014). This study addresses a gap in the knowledge about how the student-generated animations may contribute to student learning of chemistry.

This thesis reports on students' learning during the creation of animations to represent their views of a fundamental chemistry concept: states of matter. The study involved 28 high school students in one private school in Turkey. With the guidance of their teacher, the students interacted in pairs or groups to create their own animations and then discuss these animations with their classmates. They also analysed and discussed animations produced by experts.

Section 1.2 explains the background to the research and identifies relevant perspectives and frameworks. Section 1.3 briefly describes the objectives and scope of the study, the research questions and the research methodology. Section 1.4 outlines the significance of the study, and Section 1.5 provides an overview of the thesis.

1.2. Background to the research

Animations are reported to be helpful in science education by contributing to the development of students' conceptual understanding (Barnea & Dori 1996; Kozma & Russell 1997; Wu, Krajcik & Soloway 2001). Several authors have written about the use of animations to develop understanding of science concepts in particular (Ainsworth 1999; Carolan, Prain & Waldrip 2008; Danish & Phelps 2010; Tytler, Peterson & Prain 2006; Wu, Krajcik & Soloway 2001). Other researchers have focused on animations developed by themselves or other experts and their use to visually demonstrate scientifically acceptable concepts to students (Barak, Ashkar & Dori 2011; Barnea & Dori 1996; Dori, Barak & Adir 2003; Hubscher-Younger & Narayanan 2007; Williamson & Abraham 1995). While these studies are valuable, there is still little research into students creating their own animations to support science learning (Chang & Quintana 2006; Danish & Enyedy 2007; Hoban et al. 2009; Hoban & Nielsen 2014; Namvar, Rastgoo, Sattary & Payam 2011; Udo & Etiubon 2011).

Viewed from the theoretical perspective of social constructivism (Richard & Audrey 2004), student-generated animations can play a role in science education. The key proposition of social constructivism is that learning is an active process of creating rather than acquiring knowledge (Duffy & Cunningham 1996), and it is positioned as a social activity rather than an individual activity. Representational pedagogy and analogical reasoning are additional theoretical frameworks that support this thesis. The application of these theoretical approaches to the study will be discussed in Chapter 2.

The social constructivist approach adopted in this study emphasises the importance of social interaction in the construction of meaning and suggests that learning involves the interactive processes of sharing, discussion and negotiation. Social interactions give shape to students' animations because students develop their understanding of scientific animations through interaction and negotiation with their teacher and peers in activities within their classroom community (Danish & Enyedy 2007). The conjecture of this study is that students who work in groups to create animations that represent their conceptions, when they are supported by their teacher to discuss and analyse their animations with their peers, develop their understanding of science concepts.

The teacher in this study encouraged students to improve their animations and their understanding of a fundamental chemistry concept while they were creating and analysing their animations. In Vygotsky's terms, the teacher operated as the more knowledgeable other (MKO) in the class and scaffolds learning so that students operate in the zone of proximal development (ZPD) (Vygotsky 1978). ZPD is 'the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance, or in collaboration with more capable peers' (Vygotsky 1978, p. 86). Barlex and Carre (1985) argue that to be consistent with working within Vygotsky's ZPD it is essential that teachers should help students to give expression to their own ideas in the learning process. For the visual materials used in learning especially, students need assistance in becoming aware of what to attend to and what to ignore (Barlex & Carre 1985). In this study, the assistance of both the teacher and the group influenced the final form of the students' animations.

A representational construction framework (Tytler Prain, Hubber & Waldrip, B 2013c) informed the pedagogical approach adopted in this study. This framework explains how and why representational construction supports students' learning in science. In this study, the main focus of this approach is its contribution to knowledge about this pedagogical approach including, students' engagement with student-generated representations in science learning (Prain & Tytler 2013). This study employs a 'representational challenge' (Tytler et al. 2013c, p. 59) to initiate and enrich discussions that generate scientific understanding. The aim of the representational challenge is 'to build students' representational resources associated with key science concepts' (Tytler, Hubber & Prain, et al. 2013a, p. 51). The challenge in this study was for the students to use animations to represent their views of states of matter.

The principles of analogical mapping (Gentner 1983) also play an important role in the analysis of student-generated animations. Aubusson and Fogwill (2006) argue that it is important for a teacher to cooperate with students as they generate their analogies together (animations in this research), not by telling students what to present but by asking questions about their analogies and exploring their views. This includes requiring students to explain and elaborate the ideas they have about science phenomena, the reasoning underpinning these views, and the ways in which these ideas are being illustrated in their analogical representations. Even though it is difficult to create student-generated analogies, once students create an analogy their science understanding improves and they can interpret the analogies independently (Aubusson & Fogwill 2006; Cosgrove 1995; Fogwill 2007; Aubusson & Fogwill 2006; Harrison &Treagust 2006). The next section explains the research objectives and scope of the study.

1.3. Research objectives and scope of the study

The study set out to investigate the ways in which student-generated animations contributed to students' learning processes in chemistry. It aimed to answer the following questions:

Main Research Question:

How do student-generated animations contribute to students' learning in chemistry?

Sub-questions:

1. In what ways do student-generated animations influence conceptual learning?
2. How do interactions among students influence learning when creating animations?

3. How do interactions between teachers and students influence learning in the animation creation process?
4. How do analysis and discussions of the animations contribute to students' learning?

The study involved an intervention based on sociocultural theory (Vygotsky 1978), representational construction approach (Tytler et al. 2013) and analogical mapping (Gentner 1983). It was designed to explore how students use their animations in their learning of science. The specific interventions were negotiated with their teacher and took into account the contexts of individual classes. The interventions targeted the development of key concepts of the states of matter that the teacher was addressing at the time the research was conducted in the school. The intervention consisted of a lesson sequence of four phases: training in the software program, creating animations, class discussions, and reflective discussion.

Phase 1 of the intervention was training of the students to use the animation software program, K-sketch, which allowed them to use simple Flash animation to create dynamic animations from their static sketches. This continued into Phase 2, where students created animations in pairs or groups of three to represent their conceptions of states of matter. The teacher supported the students to organise and discuss their related Chemistry ideas as they generated their animations. The animation creation phase was followed by Phase 3, a class discussion in which they first analysed and discussed their own and their classmates' animations, before analysing and discussing a sample of animations that had been produced by experts. The teacher invited them to comment and critique their own animations and those of experts. After this teaching intervention, in Phase 4 the teacher led a reflective discussion about learning process that they had been involved in the preceding lesson sequence.

Chapter 3 explains the study's mixed-method research methodology, in which a combination of quantitative and qualitative methods were used. Pre- and post-tests were used as indicators of possible changes in students' understanding of the chemistry concepts. Elements of design-based research and a case study methodology also informed the research design. Design-based research principles suggested the construction of the conjecture and the use of an intervention to test the conjecture. The case study method informed the selection of a case for the application of the intervention and data gathering.

A wide range of data were collected during the intervention activities. Students responses to pre- and post-intervention tests were collected. Students were observed in class during the process of creating their animations. Discussions with group partners and the teacher were audio- or video-taped during these classes. Students were interviewed about their perceptions of their learning during the intervention and about the role the teacher played. These interviews were audiotaped. The teacher-guided follow-up classes in Phases 3 and 4 were video-recorded. The teacher was also interviewed about her experiences and perceptions of the intervention. All audio and video recordings were transcribed and translated from Turkish to English. The data transcripts were analysed and reported in English. Pre- and post-test data were analysed quantitatively using Wilcoxon signed-rank test.

Throughout the animation creation process, students were encouraged to show in their animations the understandings of the chemistry concepts that were negotiated in their group . The analysis of student-generated animations together with interactions with their teacher and group partners were used to interrogate student learning and demonstrated the pedagogical processes that influenced this learning.

1.4. Significance of the study

In chemistry education, students need to understand the dynamism of chemical changes and the structures of molecules (Ben-Zvi, Eylon & Silberstein 1986; Harrison & Treagust 2000). Animation software programs about chemical concepts involving dynamic process and motion may play a role in helping to develop this understanding. Research focusing on the effectiveness of computer-based representations has found that such representations help students in their conceptual understanding of chemistry (Ainsworth 1999; Prain & Waldrip 2008; Tytler, Peterson & Prain 2006).

However, there has been little research into the efficacy of how students create animations of scientific concepts (Ardac & Akaygun 2004; Hoban & Nielsen 2014; Kozma & Russell 1997; Kozma, Chin, Russell & Marx 2000; Tytler 2000; Udo & Etiubon 2011) and especially concepts in chemistry (Hoban & Nielsen 2010; Hoban et al. 2009; Hubscher-Younger & Narayanan 2007; Prain & Waldrip 2008). This study aimed to investigate the ways in which student-generated animations supported students' learning in chemistry. Previous researchers have shown the effects of student-generated animations on conceptual understanding and have offered pedagogical reasons for creating animations, such as enjoyment, motivation, interest and engagement (Chang & Quintana 2006; Vermaat, Kramers-Pals & Schank 2003). Other studies have explored how student animations influence effective learning (Barnea & Dori 1996; Carolan, Prain & Waldrip 2008; Kozma & Russell 1997; Wu, Krajcik & Soloway 2001,). However, the way the software programs, teacher support and peer collaborations in combination can help students' learning and thinking processes has rarely been reported in the literature.

This thesis makes the following conjecture:

> When students work in groups to create their own animations to represent their conceptions supported by their teacher and discussions to analyse animations, they will develop understanding of science concepts.

It argues that generating student animations combined with interactive discussions creates an opportunity to represent dynamically the elements of students' conceptualisations about the states of matter. The study seeks knowledge about the strengths and weaknesses of the selected animation program for students' learning and makes recommendations about effective teaching strategies and learning environments. In addition, this research sets out to extend knowledge of the role played by discussions during and after student-generated animations. The findings of the study have implications for science teaching.

1.5. Overview of the thesis

The thesis has five chapters. This section gives a short overview of the four remaining chapters.

Chapter 2 reviews the research literature relevant to science learning through the use of student-generated animations. It also explicates the theoretical frameworks underpinning this study, namely, social constructivism, sociocultural theory, representational pedagogy and analogical reasoning. Previous research about the multiple facets of representations and the use of ICT while enhanced science learning is also identified and discussed.

Chapter 3 provides background information and establishes the context of the research. It explains the methodology used in this research and the methods of data collection and analysis. The trustworthiness of the research methods is discussed and the researcher's field questions briefly explained. Information regarding ethical conduct of the research is also presented.

Chapter 4 presents the data collected from the study in one school in Turkey. Students' pre-and post-tests results are reported, as are the audiotaped and videotaped data from the intervention. Findings specific to the four phases of the intervention are presented in separate sections. These findings provide information relevant to each of the research questions and form the basis of the discussions in Chapter 5.

Chapter 5 addresses the main research question and each of the four sub-questions. The implications of the study for science teaching and learning are discussed. Potential areas for future research are then identified before the concluding statement about the research is elaborated.

Chapter 2: Literature Review

2.1. Chapter overview

This chapter analyses previous research relevant to student learning with generated animations in science. In particular, it considers research on the role of representations, animations and student created animations in science learning. It locates this in Vygotsky's sociocultural theory and representational challenge. This chapter also clarifies key points within the relevant literature to the research. In outlining the theoretical foundation for this study, the chapter draws on social constructivism development in science representation.

The remainder of this chapter is divided into five sections. Section 2 examines the theoretical framework for the research. This section has a discussion of Vygotsky's (1978) sociocultural theory about active learning processes through interaction with partners and interaction with teachers and how it might be appropriate in science education. In addition, it explains the representational construction approach with its four main principles. The key element of the representational construction approach is 'Representational Challenge', which provides a central perspective for this study. Analogical mapping is also discussed as a basis for mapping student animations against other representations and conceptualisations. Section 3 discusses the representations and defines the terminology used by providing examples from the literature. Different forms of chemical representations are highlighted in this section. Section 4 discusses research on using technology and animations in school science. In this section, the effectiveness of information and communications technology in contributing to students' visualisation and students' learning is considered. Section 5 reports on the use of student-generated animations, providing examples from the literature. Section 6, the conclusion, provides a synthesis of the theoretical and pedagogical frameworks used in framing this research.

2.2. Theoretical framework

The theoretical framework of this study is underpinned by sociocultural theory and research in the fields of representational construction and analogical reasoning. Each of these is now discussed in order to elaborate elements that are critical to this study of the teaching and learning of science through student-generated animations.

2.2.1. Sociocultural theory

This study draws on a social constructivist approach to learning, which is influenced by Lev Vygotsky's (1978) sociocultural theory. According to a constructivist perspective, learning is a process of active constructing by students, and new knowledge is constructed on a framework of previous understanding. Students add new observations and experiences into their existing mental models and actively use their existing knowledge to build new understanding and knowledge of the world (Ernest 1998; Gredler 1997; Maxim 2013; Prawat & Floden 1994).

Application of the general principles of constructivism into social settings is called social constructivism. Social constructivism focuses on learning where individuals interact in a group to construct knowledge for one another, collaboratively creating a small culture to solve a given task through shared meanings (Richard & Audrey 2004). It emphasises that culture plays a significant role in the cognitive development of a person and that individuals create meaning during their interactions with each other and with the environment (Ernest 1998; Gredler 1997; Prawat & Floden 1994).

Critical to social constructivism is that learning and knowledge are constructed, and social interactions play a fundamental role in the development of cognition and learning. For Vygotsky (1978), everything is learned on two levels: through interaction with others, and integration into the individual's mental structure.

> Every function in the child's cultural development appears twice: first, on the social level, and later, on the individual level. In other words, first it appears among people and then appears inside the child's mind. This applies equally to voluntary attention, to logical memory, and to the formation of concepts. All the higher functions originate as actual relationships between individuals (p. 57).

Another aspect of Vygotsky's (1978) sociocultural theory is *the zone of proximal development* (ZPD), which he describes as a zone where learning occurs in a supportive learning environment. He defined the zone of proximal development as

> The distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more knowledgeable others (p. 86).

There is a gap between the actual competence level of students and their level of potential development. Actual competence level is characterised by the problems students can solve independently and the potential development level characterised by the problems students can solve only under adult guidance or interaction with more capable peers. The main features of ZPD are assistance and experience at the level students can experience, and they can learn. Students have an existing level of understanding and need assistance to reach the next level. Where useful instruction or guidance is given to students, they can develop higher mental functions (Vygotsky, 1978). Students who have less experience with a concept or an area will need more guidance than the students who have had more experience with that concept or area (Oakes & Lipton 1999).

The expression, *more knowledgeable other* (MKO) refers to anyone who has better understanding or a higher knowledge level than the learner, with respect to a specific concept, task or process is able to provide the learner scaffolds (Maxim 2013, p. 135). The MKO is often a teacher or older adult, or it may be a peer, a younger person, or these days a computer. In the classroom environment, the teacher becomes the supporting MKO for students in the ZPD and scaffolds the learning by helping them to connect new knowledge to existing knowledge (Maxim 2013). According to Vygotsky (1962), scaffolding is integral to ZPD because it assists the interactions between MKO and learner in the learning process. Students first try what they can do individually and then what they can do with assistance from their MKO (Powell & Kalina 2009). Students learn the new concepts based on what they can do on their own.

Scaffolding occurs when students are asked to perform a task and support is provided by the teacher to enable them to complete the task. An example might be learning the alphabet. When students learn the alphabet they might miss a letter, but they can learn to correctly recite the alphabet on their own if their teacher repeats the alphabet aloud together with the student while showing the missing letter in a different colour.

A feature of social constructivist theory and Vygotsky's sociocultural theory is collaboration and learning with peers. The critical point here is creating a social environment for learners. Vygotsky (1981) asserted that children learn through their interactions with others, so students should work not only with a teacher (MKO) but also other students; they can exchange and test many different ideas in collaboration with others.

Vygotskian emphasis on peer collaboration in learning is broadly consistent with the principles of cooperative learning. Cooperative learning has been described as a kind of small group instruction in a social setting in which students solve the given tasks (Slavin 1990). In cooperative learning, students work not only with their teacher but also other students with whom they exchange many different ideas. When they work together on activities or tasks in a group, each member of the group may have a different internalisation of knowledge depending on their existing knowledge because knowledge is constructed on learners' previous knowledge, experience and background (Doolittle 1995; Powell & Kalina 2009; Doolittle 1995; Sharan 1990).

These theoretical concepts involving the active constructing of knowledge by students, interactions with the teacher and students, ZPD with scaffolding and MKO, and cooperative learning activities can guide teaching and learning any flexible classroom environment. The next section explains the representational construction approach that supports this study.

2.2.2. Representation Construction Approach, Representational Challenge

In this section, the principles of the representation construction approach and how representational construction supports science learning are explained. Representational challenge will be also discussed as a pedagogical manifestation (or strategy) of representational construction in science teaching and learning.

Representation construction approach

Representation construction is based on learning as 'meaning making', which is consistent with the social constructivist theory of learning. There are four main principles of the representation construction approach to teaching and learning (Tytler et al. 2013a, b, c). Before explaining the principles in detail, some analysis of the perspectives and principles is now represented.

Many researchers have focused on the effectiveness of multiple representations to develop conceptual understanding in science (Ainsworth 1999; Carolan et al. 2008; Saul 2004; Wu et al. 2001). Waldrip and Prain (2013) state that understanding different representations and their translations into one another, and understanding their proper usage are critical to science education. Students are required to represent and translate their learning with multiple representations in order to reach conceptual understanding in science learning (Ben-Zvi et al. 1986; Harrison & Treagust 2000). While there is extensive research on students' learning from expert representations (Barak et al. 2011; Barnea & Dori 1996; Dori, Barak & Adir 2003; Kozma & Russell 1997), the body of work investigating students' own representations for learning is less well developed. The representational construction approach provides a contribution to knowledge about students' engagement with their own representations in science learning, especially in junior secondary school (Prain & Tytler 2013). Reporting on the use of the representational construction approach, Waldrip and Prain (2013) write:

> Students and teachers generated various representations of target concepts, and knowledge construction was viewed as the process of making and transforming these different representational modes, as they scaffolded understandings in relation to their perspectives of the real world. (p. 16)

Waldrip and Prain's (2013) approach uses multiple representations of conceptual understanding for effective science learning. A key feature for effective learning they identify is 'reaching general classroom negotiation of representational understanding' (p. 16). Students need to explain their representations to reveal their understanding of concepts. They are expected to develop key science ideas through multiple representations and these are reported and scrutinised in classroom discussions. Waldrip and Prain (2013) conclude:

> Students learn most effectively in science and engaged more, where they were challenged to develop meaningful understandings, where individual learning needs and preferences were catered for, where a range of assessment tasks were used, where the nature of science was represented in its social, personal and technological dimensions. (pp. 16-17)

These findings are consistent with earlier research conducted by Tytler, Waldrip and Griffiths (2004). When Tytler et al. (2013c) began work on representational research, they were aware that representations are used extensively in science classrooms. However, they wanted to know more about teachers' understandings and perspectives of how to use different representational modes in science topics to promote learning and to motivate students. Initially they surveyed 20 teachers after they had been involved in an intervention promoting use of representation in science class to obtain information about teachers' beliefs and practices regarding the usage of different representations in science teaching and learning. They also conducted four individual case studies of teachers to explore the role of representations in science classes and then created a framework from those studies for the representational construction approach. They also researched the effects of representational work on students' engagement, conceptual learning and capacity to organise representations. Findings from their survey with 20 teachers indicated that teachers

- mostly focused on resources and students' learning styles rather than multi-modal representations
- thought that different representations should be used for the same topic because not every model is suitable for every student, and some models are better than others for some students
- thought using these multiple models make the topic more tangible
- became aware of different modes of representations
- perceived that a representational approach increased students' interest
- used different modes of representations but did not focus on any particular modes as being correct (Waldrip & Prain 2013, p. 18).

Analysis of these survey results and case studies showed that there were challenges for teachers in employing a representational construction approach. The teachers found that this approach initially could be more time consuming than their usual teaching method but they recognised the significant achievements in the quality of student learning that emerged. They also became aware of individual students' needs and differences in their understanding. Teachers noted that there was a lack of representational resources for the development of teaching and learning sequences. Some thought that this approach was limited because they were concerned that all students did not possess the cognitive tools needed to create representation of some science concepts that were part of the curriculum they studied (Waldrip & Prain 2013).

The representational construction approach also improved learning by providing multiple representations, which taught students to create representations in time frames. In general, the teachers claimed that the representational approach had benefits for teaching and learning. It improved construction of knowledge by students, improved student engagement and achievement, provided different perspective for students' thinking and was 'productive, diagnostic and formative' (Waldrip & Prain 2013, p. 25).

The teachers involved in Tytler et al's (2013a) case studies and surveys identified a range of conditions for the effective use of the representational construction approach. These include:

- The task and the representational work should have a strong fit with each other.
- Strong teacher scaffolding is required.
- Teacher guided public negotiation of representational adequacy is required.
- Students need to understand the purpose of representational adequacy and create links for their understanding (Waldrip & Prain 2013, p. 26).

Finally, Waldrip and Prain (2013) claim that students could have difficulties or limitations when representing the concepts in two dimensions. Technology could promote 'mastery skills' (p. 27) that indicates students' understanding in science concepts while they were creating their own representations.

Tytler et al. (2013b) developed principles for the representation construction theory that take into account the analysis given here. These principles underpin the representational construction approach to teaching and learning, including a learning process for both teachers and students. The four principles of the representation construction approach will now be outlined.

The first principle is: 'Teaching sequences are based on sequences of representational challenges' (Tytler et al. 2013b, p. 34). Students actively create representations to explore and make claims about phenomena. Teachers explain key concepts, important ideas and their representations to guide students in the beginning stage of a topic. Students are supported to explore before they are given the canonical forms and to use models to organise representations, improve their representations and solve problems. There is a back-and-forth between student-generated representations and teacher-introduced representations that encourages and challenges students to improve and organise their understanding.

The second principle is: 'Representations are explicitly discussed' (Tytler et al. 2013b, p. 35). Teachers have two roles during class discussions, namely, to support students' own representations and to provide scaffolding. In these discussions, students are helped to understand that multiple representations are necessary when using aspects of a concept, and that in a guided process, group agreement on 'generative representations' (p. 35) also assists the resolution of a problem. Teachers' scaffolding and classroom discussions are necessary both during and after constructing representations.

The third principle is: 'Meaningful learning involves representational/perceptual mapping' (Tytler et al. 2013b, p. 35). Students have a task in strong perceptual contexts. They are supported to make mapping or reasoning between visible features of objects, likely implications and representations activities. Student engagement in perceptual context is important. Activity sequences need to engage students in learning as personally meaningful and challenging, according to students' interests and values.

The fourth principle is: 'Formative and summative assessment is ongoing' (Tytler et al. 2013b, p. 35). Students and teachers continuously evaluate the process to assess the sufficiency of representations and their explanations of them . Formative and summative assessments allow students to generate further representations. Support is also essential for students to coordinate and re-present multiple modes during the learning process. The approach behind these principles presents significant challenges for both students and teachers. These representational challenges are explained in the next section.

Representational Challenge

Representational challenge is central to the representational construction approach and it underpins its second principle, namely, 'Representations are explicitly discussed' (Tytler et al. 2013b, p. 35). It includes construction of students' own representations, discussion and improvement of these representations in a class environment, and the role of representation in learning and knowing. It involves a new organisation or synthesis of existing representations, and is related to how a concept or phenomenon should be represented and explained. It also acknowledges individual differences in the ways students transfer their thinking to their representations and explain their representations.

The first part of a representational challenge occurs when students create their representations, explain them or comment on what they did or did not represent, and how their representations are related to each other. All these are parts of the 'challenge.' Students are challenged to make a reasoned claim about the phenomena they are studying. It is important that students learn to put forward not only their reproductions of known representations, but also the challenges they will face in the interpretation, synthesis and organisation of representations of new phenomena (Tytler et al. 2013a).

The second part of representational challenge includes ‘class or group discussions.’ In most cases, representational challenges are group work; they compare, contrast and discuss the group’s responses to a challenge. They involve the relationship between students’ representational responses in small groups (or as individuals) by creating representations. The teacher plays an active role during the discussion by questioning, shaping and assessing students’ representations. These teacher-guided discussions in the classroom environment ‘generate and clarify meaning’ (Tytler et al. 2013c, p. 61) and cause ‘shared understanding of the appropriateness and efficacy of various representations, and their role’ (p. 51).

While students need to explain key ideas through multiple representational modes linked to science phenomena and share their personal work and experiences with their classroom, teachers too are challenged to develop their understandings of the science concepts when planning and organising representational work. They need to decide what representational abilities would be satisfactory for students’ learning and to provide scaffolding to students for their active roles in the construction of multiple representations (Waldrip & Prain 2013).

This section has introduced key aspects of sociocultural theory, social constructivism and the representational construction approach relevant to this research. In the next section analogical mapping will be discussed. The principles and findings of research in representational construction approach have much in common with science education research into analogical thinking. It is therefore appropriate to consider the role of analogy in science teaching and learning.

2.2.3. Using analogies in science instruction

An analogy is ‘a partial similarity in particular circumstances on which a comparison may be based’ (*Macquarie Concise Dictionary* 6th ed. 2013). In science education the meaning of analogy is extended to include ‘the process of identifying similarities between two concepts … [and] abstract ideas in familiar terms’ (Aubusson, Treagust & Harrison 2009, p. 200). Used in this way, analogies clarify, illustrate and construct meaning by making the unfamiliar (what one is trying to explain) familiar in terms of ideas that are analogically similar.

Analogies create relations between previous familiar knowledge and experiences and new contexts and problems (Harrison & Treagust 2006); they open new perspectives for students from teachers' perspective (Venville & Treagust 1996). Analogies help students to understand complex, abstract concepts by creating opportunities for them to compare real world similarities with new or abstract concepts (Treagust, Harrison, Venville & Dagher, 1996). Students are then able to develop a more scientific understanding of concepts, especially abstract concepts, because analogies provide new material that can be easily integrated to students' existing knowledge (Duit 1991).

Why do teachers need to use analogy in science and chemistry teaching? When used appropriately, analogies are especially effective for explaining relations between scientific ideas and 'ideas that students find familiar' (Coll 2006, p. 73) and for illustrating and modelling abstract or difficult scientific concepts such as:

- atomic bonds and the conservation of matter (Coll 2006; Coll & Treagust 2002; Duit 1991)
- fundamental chemical concepts such as solubility (Taylor & Coll 2002)
- the use of complex instrumental techniques such as nuclear magnetic resonance spectroscopy (Coll 2006)
- molecular structure, chemical reactivity and equilibria and stereochemistry (Coll 2006).

An analogy has two attributes: the base analog and target analog (Aubusson et al. 2009). The familiar concept (which is used to facilitate the explanation) is called the base analog, and the unfamiliar concept (which is to be explained) is called the target analog. Target and base analogs have certain features that can be mapped as being similar and dissimilar, both types needing to be identified. Mapping is described as 'the intellectual process of identifying attributes of the analogy and the analysis of the match and mismatch of each attribute' (Aubusson & Harrison 2006, p. 4). According to Niebert and Gropengiesser (2014), the mapping process requires reflection on highlighting and hiding.

It should not be assumed that students are able to map the shared attributes of the target and base analogs without their teacher's support (Coll 2006). Aubusson et al. (2009)

claim that when using analogies effective learning occurs when the teacher assists students to map the features of the target and base analogs. The teacher needs to discuss and explain the similarities and differences in the target–base analog relationship. The explanation and discussion of analogies are more valuable in learning than the analogy itself. Even though an analogy may sometimes not represent a phenomenon accurately, the explanation of its match and mismatch properties helps create understanding of that phenomenon (Aubusson & Fogwill 2006; Fogwill 2007). Niebert & Gropengiesser (2014) showed that even students and scientists use the same analogies but they map them differently. The thinking and discussions that occur during mapping are crucial to understanding related science concepts (Fogwill 2006).

Analogical research in science education has shown that when students interpret analogies on their own they often generate misconceptions about the scientific concepts (Harrison & Treagust 2006). For example, Vosniadou and Schommer (1988) showed that even though five- and seven-year-olds were able to find the similarities between target and base analogs, students are less likely to develop misunderstandings when they work with their teacher during the mapping of the similarities and differences of the analogies.

The use of student-generated ideas is crucial in analogical mapping. Justi and Gilbert (2003) suggest that teachers should discuss and guide rather than show and tell so that students are able to construct their own analogies. When students discuss their student-constructed analogies, they are more likely to be able to map their own analogies than the analogies provided by their teacher (Harrison & de Jong 2005; Harrison & Treagust 2006). When students create an analogy, they use their own familiar concepts (base analog) to represent the unfamiliar concept that is to be explained (target analog). Self-generated analogies can deepen their understanding of science because once they create an analogy, it is easier for meaningful learning to arise (Aubusson & Fogwill 2006; Cosgrove 1995; Fogwill 2007). Even though students find it difficult to build their own analogies, when they do so, they can map it easily (Harrison & Treagust 2006).

Aubusson and Fogwill (2006) say that while students' own independent analogies may lead to misunderstandings, when a teacher works with students to co-design and ensure careful mapping, sound concept development is a consistent outcome. Explanations and discussions about matching and mismatching properties make analogies powerful learning tools. Students generating their own analogies provides an opportunity for the teacher to intervene to highlight when clear understanding exists. Careful questioning deepens understanding because students can build on and modify an existing cognitive framework.

Aubusson et al. (2009) argue that using analogies along with the mapping of the match and mismatch of each attribute can contribute to effective science teaching and learning. To maximise the advantages and minimise the limitations of analogies, Treagust, Harrison and Venville (1998) recommended a guideline for teaching analogies, which they called the FAR guide (see also Harrison & Treagust 2000). The guideline has three stages: pre-lesson *focus*; in-lesson *action*; and post-lesson *reflection* (see Figure 2.1).

The FAR Guide for Teaching with Analogies and Models

Pre-Lesson FOCUS	
CONCEPT	Is the concept difficult, unfamiliar or abstract?
STUDENTS	What ideas do the students already have about the concept?
EXPERIENCE	What familiar experiences do students have that I can use?
In-Lesson ACTION	
	Check student **familiarity** with the analog
LIKES (mapping)	Discuss ways in which the analog is **like** the target
	Are the ideas surface features or deep relations?
UNLIKES (mapping)	Discuss ways in which the analog is **unlike** the target
Post-Lesson REFLECTION	
CONCLUSIONS	Was the analogy clear and useful, or confusing
IMPROVEMENTS	What changes are needed for the following lesson?
	What changes are needed next time I use this analogy?

Figure 2.1: The FAR guide (Treagust et al. 1998)

In the 'Focus' stage, the teacher decides whether or not students are familiar with the concept: Do they know something about the concept that is to be explained? This gives the teacher some ideas of the kinds of difficulties the teacher and the students may have during instruction In the 'Action' stage, the teacher discusses in class presentations the similar and different features of the target and base analogs, and the suitability of the analogy in explaining a science concept. The 'Reflection' stage takes place after the analogy has been shown in class. The teacher draws a conclusion after considering the benefits and constraints of analogy, discussing with the class how to improve the lesson using the analogy, and asking students to reflect on the lesson. These steps do not have to be distinct; they can be woven together throughout the process of working with the analogy (Treagust et al. 1998; Aubusson et al. 2009).

In summary, analogies are powerful tools in science education. Analogies help teachers to understand and express the concept being taught and to guide students in their process of understanding. According to Cosgrove (1995), the best analogies are student generated. However, without teacher support, analogies often create misconceptions for students (Harrison & Treagust 2006). When analogies are used effectively, as with the FAR guide, for example, they are valuable in teaching because they provide an easy way of explaining abstract concepts using familiar concepts. Students need to understand and map the analogies, while being aware that analogies are approximations of some reality (Coll 2006).

So far in this section, a range of theoretical approaches has been discussed. It may be useful to present a summary of how they are connected. In the following paragraphs the relationship between the representational construction approach and sociocultural theory is described.

The principles of the representational construction approach are consistent with learning view in terms of Vygotsky's sociocultural theory. Firstly, representational construction approach based on productive use of students' own representations for learning and students are active learners who construct their own understanding (Maxim 2013; Ernest 1998; Gredler 1997; Prawat & Floden 1994). Secondly, in representational construction work, a teacher's function is more knowledgeable person, MKA (Vygotsky 1978). The teacher becomes the supporting tool for students to provide scaffolding (Vygotsky 1978). Students firstly create representations alone or with peers and then extend their understanding through guided public negation by the teacher. There is a need for strong scaffolding in the representational construction approach based on teachers' perspectives. In addition, Vygotsky asserted that during scaffolding in ZPD, each individual has a unique type of internalisation to attain the idea. Tytler, Waldrip and Griffiths (2004) also found that students learn most effectively where their individual needs were met. In the representational construction approach, the teachers also agreed that representational construction depends on each students' own ability linked with other subjects supported by each individual's internalisation.

Representational challenge is also consistent with Vygotsky's (1978) theory. Tytler et al. (2013a) argue that effective learning in science always occurs with students' knowledge-production processes. Students construct their own knowledge actively and they need 'scaffolding' (Vygotsky 1978) during the construction process. In addition, group work and negotiations underpin Vygotsky's (1978) cooperative learning because representational construction mostly uses group work to challenge student representations. Cooperative learning also uses small group work to solve a given task in a social setting (Slavin, 1990). According to Vygotsky (1981), children learn by interactions with others and also teachers work with students in cooperative learning. Students have discussions with each other, exchange their ideas during group work and also get support from their teachers when they need in cooperative learning. The representational construction approach uses students' representations along with their discussions, negotiations and collaborations in group work. This allows representational construction and cooperative learning to have a strong fit with each other.

The next section discusses the representations in science and especially chemistry teaching by providing examples from the literature.

2.3. Representations

In this section, representations of different levels of chemical concepts will be discussed by providing examples from the literature. Mastery of chemical concepts involves understanding three levels of chemistry: macroscopic, microscopic and symbolic (Johnstone 1993). The macroscopic level includes chemical phenomena that we directly experience in our daily lives or in the laboratory (Gabel 1999; Treagust, Chittleborough & Mamiala 2003). It refers to observable and tangible chemical phenomena such as a colour change or the heat felt and light seen in burning a match. For example, at the macroscopic level there are many directly observable attributes when silvery liquid mercury mixes with a red-brown bromine liquid. Observable changes include a colour change and the appearance of white crystals. The microscopic level deals with how atoms and molecules behave during physical and chemical changes such as the combination of mercury (Hg) atoms with bromine (Br2) molecules to form mercury (II) bromide (HgBr2) molecule in a regular array. At this atomic and molecular level the changes in the arrangements of atoms cannot be directly observed. The chemistry is abstract and far from the direct sensory experience of students. The microscopic level of changes occurs in the particle level, so this level is also described as the molecular or particulate level. The symbolic level refers to representations of chemical phenomena using a variety of media including symbols, mathematical formulae, drawings, models, equations (Chittleborough, Treagust & Mocerino 2002) such as the chemical symbols used for elements and compounds (e.g. Hg, Br), or its properties and behaviour (e.g. +, →, (g)) (Talanquer 2011).

Chemistry educators and researchers have long been seeking effective ways to help students to develop their understanding of chemical concepts (Ainsworth 1999; Carolan et al. 2008; Danish & Phelps 2010; Tytler et al. 2006; Wu et al. 2001). In the conceptual understanding of chemistry, one of the most important skills is the ability to understand and explain relationships between the macroscopic and microscopic level. Students are required to represent and to translate chemical problems across these levels in order to both develop and to communicate their conceptual understanding (Ben-Zvi et al. 1986; Harrison & Treagust 2000). However, the literature shows that many students have difficulty in understanding chemical representations because of the abstract, unobservable and particular nature of chemistry at the microscopic level (Barnea & Dori 1996; Wu et al. 2001).

Kozma and Russell (1997) also suggest that the microscopic level of chemistry is problematic for students, who often struggle to explain chemical phenomena at this level. In addition, a sound understand of chemistry requires agreement about the three levels of representation and the ability to learn chemistry with symbolic representations, but students often use symbolic representations without understanding the meaning of the chemical concepts associated with these representations (Nakhleh 1993; Nurrenbern & Pickering 1987; Sawrey 1990 cited in Wu et al. 2001). For example, students use the symbolic formula of water as H_20, to represent a molecule of water but they have difficulties in conceptualising water molecules when they see water in a beaker full of water. In other words, students experience problems mapping relationships of chemical representations across different chemical levels (Gabel 1999).

Chemical representations take different forms, formulas, structures, symbols, or metaphors across these chemical levels (macroscopic, microscopic, and symbolic), but the literature consistently shows that students have problems understanding varied representations in chemistry. Barnea & Dori (1996) have therefore recommended that teachers show and elaborate on the connections across multiple forms of representations to support learning of students in chemistry classrooms. In one example, they reported on a study in which molecular modelling with geometric and symbolic representations were all used concurrently to illustrate the chemical structure and bonding of molecules. The results showed that students who studied the geometric and symbolic representations of molecules with molecular modelling software achieved higher scores on chemical structure and bonding concepts questions than the control group of students who studied the subject in the traditional way. Their study also implied that working with different representations of molecules, geometric and symbolic, improved students' three-dimensional perceptions and helped them to clarify a relationship between the molecular formula and geometric structure of molecule.

Chemical representation types, other than symbolic representations, including physical models, allow students to develop their mental models in the macroscopic world and to manipulate concrete objects representing of individual atoms and molecules. Students have mental models of chemical phenomena. When they construct concrete models they compare the fit between the mental and physical models and may alter each to ensure a closer match (Stieff, Bateman & Uttal 2005). It can also be implied that physical models such as ball and stick models act as a visualisation tools for students.

Visualisation tools can help the students' conceptual understanding in chemistry by making connections across the macroscopic, microscopic and symbolic levels to represent aspects of the same phenomena at different levels (Ferk, Vrtacnik, Blejec & Gril 2003). Visualisation and learning with representations can promote students' understanding, particularly in chemistry education (Eilam & Poyas 2010). Rapp (2007) stresses the importance of visualisation in the learning of chemistry. He argues that visualisation, makes learning active for students, increases student engagement with chemistry and promotes interactivity among students, all of which contribute to the construction of mental models during the learning process.

Despite the fact that physical models offer some assistance in the teaching of chemistry, research suggests that teachers need to be cautious when they are using different kinds of representations such as physical models because representations can be open to misinterpretation. For example, ball-and-stick representations can be used to build three-dimensional conceptualisations of molecules and contribute to the sense of the molecule as a three-dimensional image and the relative size of each atom. However, there is a risk that students may assimilate inappropriate attributes of the representation, such as the spherical structure or colour of the balls in the molecular models, and generate misconceptions (Harrison & Treagust 2000). In addition, there can be inaccuracies in the angles or bond lengths of molecules (Barnea & Dori 1996). Therefore, teachers should emphasise that representative models are limited to particular attributes of phenomena and scientific ideas (Ferk et al. 2003). Physical models in the science-education context are tangible, easily observable models of chemical situations. However, the use of physical models is also restricted and limited in the classrooms as students cannot always create concrete representations easily. For decades, chemistry educators have attempted to use and improve other representation types with fewer limitations for students' conceptual understanding such as computer modelling or computer-based animation. The next section considers computer-based technologies in modelling and animation.

2.4. Representations with technology and animations

In this section, the role and effects of teaching and learning with representations using information and communications technology (ICT) in chemistry education will be explained with a supporting literature review.

How molecules and atoms behave during physical and chemical changes is not easily shown and illustrated in chemistry. This microscopic world of chemistry is visually and conceptually challenging. ICT can help students to learn chemistry by allowing them to visualise chemical processes and explain unobservable concepts (Barnea & Dori 1996; Kozma & Russell 1997; Udo & Etiubon 2011; Wu et al. 2001).

In recent years dynamic ICT animations have become inescapable visualisation tools for learning science concepts. For example, ICT can help students to move between the microscopic chemical level (molecular world) and macroscopic chemical level (observable world). ICT animations can easily show the behaviour of water molecules (microscopic level) during phase change (macroscopic level) and assist students with the transition between these levels. Such transitions support higher-order and critical thinking skills and enhance the effective learning of science. (Barak et al. 2011; Dori et al. 2003; Williamson & Abraham 1995).

Studies consistently show that teachers who make use of computer-based science simulations in the instruction of chemistry concepts help students to develop their conceptual understanding and also increase their performance in chemistry tests (Chang & Quintana 2006; Hübscher-Younger & Narayanan 2007; Udo & Etiubon 2011). At the microscopic level of chemistry, showing the dynamic nature of the molecules with static pictures is especially difficult. Computer animations can show the dynamic features of a situation 'directly and explicitly' (Hübscher-Younger & Narayanan 2007, p. 235) and help students to visualise dynamic processes in chemistry (Chang & Quintana 2006). The following paragraphs detail a few of the many studies that have investigated the effects of computer animations in chemistry education.

Williamson and Abraham (1995) investigated the effects of computer animations on students' visualisation of chemistry concepts. Their study included computer animation sequences to visualise chemical processes at the microscopic level. They used the animation sequences as a visual tool in lectures and as an assigned activity in a computer laboratory. Three treatment groups included a control group, a lecture animation group, and a group that viewed the animation sequences in both the lecture and the computer discussion session. The students (N = 400) in this study were enrolled in two sections of a general chemistry course. One lecture section was randomly assigned as the experimental group, and the other was the control group. The two lecture sections received the same instruction except for the use of animations. Students were also enrolled in 16 discussion/laboratory sessions. Each section included one hour of discussion and three hours of wet laboratory per week. In addition, there were three discussion sections and the computer laboratory work was done during these discussion sections. Students viewed the animation sequences and answered worksheet questions. Students could view the animation repeatedly. Only students who missed no more than one lecture and attended all of the computer sessions were included as subjects in the lecture/computer lab animation group. Only students who missed no more than one lecture section were included as subjects in the lecture-only animation group and the control group. A Particulate Nature of Matter Evaluation Test (PNMET) instrument was used to determine the nature of the students' visualisations, including students' drawings, students' explanations, and multiple-choice explanations of concepts. Conceptual understanding was measured by the PNMET results.

Williamson and Abraham's (1995) study showed that the usage of animations was associated with an increase understanding according to scores, with 56% of the control group students, 73% of the lecture animation group and 77% of the lecture/computer lab animation group students achieving an adequate understanding of the phenomena and being able to draw microscopic views of the phenomena. In addition, 3-D computer representations allowed students to understand the micro-level dynamic interaction of the molecular structure and helped them to make connections between the physical phenomena (macro level) and unobservable abstract phenomena (microscopic level). The researchers argued that 'use of the animations caused the students to begin to think in particulate terms and to attend to more details concerning the behaviour of particles' (p. 532). Stieff et al. (2005) have also argued that 3-D representations, which include dynamism such as animations, can increase students' understanding during their learning process.

Dori, Barak & Adir (2003) investigated the effects of computer molecular models (CMM) and web-based teaching on the students' learning. Their study consisted of seven chemistry faculty and six chemistry teaching assistants, 215 students who attended three web-based chemistry courses and 53 students who participated in a survey. Participating in CMM was optional for students. The 215 students were divided into a control group (N = 120) and experimental groups (N = 95). The project included downloading two shareware programs. One of these programs was used to write the structural formula of the molecule, and the other to view and manipulate the complex molecule in three representational forms: framework, ball & stick and space filling. The experimental group students used CMM software to represent complex molecules such as vitamin A, vitamin B, vitamin C, nicotine, caffeine, adrenaline, TNT and DDT. They were asked to compute its molecular weight, to construct hybridisation and electrical charge distribution for each of the carbon atoms in the molecule and to research information about the molecules' daily use or application on the web. According to the pre- and post-test results, the experimental group students achieved higher scores than the control group and higher scores on the course final exam. The experimental group students were also able to transition across 1-D, 2-D and 3-D molecular representations better than control groups. Semi-structured personal interviews with faculty and teaching assistants showed that none of them had used information technology before for teaching a general chemistry course, but the analysis of the students' survey showed that 95% responded positively when asked about their experience with chemistry in a web-based and CMM environment. This shows that the majority of students were keen on learning chemistry with web-based sources. From the students' interviews and the researchers' observations, the researchers argued that web-based sources created an exciting learning environment and students found that web-based materials and assignments were valuable and useful in their learning. In addition, by the end of study, students' motivation to study chemistry was enhanced and their understanding of molecular 3-D structures had improved based on pre- and post-test results. Finally, the researchers' findings indicated that the web-based learning tools could contribute to students' higher order thinking.

Barnea & Dori (1996) studied the effect of CMM on students' understanding and constructing of new concepts of chemical structure and bonding. This study included three classes of 10th grade high school students as the experimental group and two classes of 10th grade students as the control group. The experimental group attended three computer laboratory classes of two hours each and worked on geometric shapes of molecules with molecular modelling software. The control group was taught using 'conventional frontal method-a deductive approach' (p. 633). Valance State Electron Pair Repulsion theory was demonstrated by using a blackboard in the classroom and rigid models in the control group. The study showed that working with the computers enhanced the motivation of most students and made learning more individual. This means that when they were deciding about the molecular structure of molecules or identifying them as polar or nonpolar, students were independent of their teachers and did not require much assistance from them. They just needed approval from their teachers when they disagreed on the shape of molecules. In addition, students who used CMM were more energetic than the control group students. Students in the control group were able to visualise molecules in different kinds of display models such as coloured lines, space filling, quick filling, and ball & stick representational models, and were 'internalising the idea that different models are just different ways of representing the same substance' (p. 633). The findings suggest that computer-based molecular modelling can contribute to a better understanding of chemical bonding and improve 3-D perception of molecular structure.

Wu et al. (2001) also examined the effects of using computerised models. They used the software program, eChem, to allow students to build molecular models and multiple representations at the same time. This study built on earlier research that showed that multiple multimedia representations allowed students to visualise the behaviours of molecules and understand the related chemical concepts (Kozma & Russell 1997). The participants in Wu et al's (2001) study were 11^{th} grade high school students who used the eChem program during a six weeks period. Students were asked to make 2-D and 3-D transitions, compare structural differences linked with 2-D structural formulas, identify types of bonding based on chemical formulas and determine polar, nonpolar molecules. The results of the study indicate that students' understanding of chemical representations improved, according to the pre- and post-tests results. The program helped students to make transitions between two-dimensional and three-dimensional models, and contributed to their understanding of isomers and the polarity concept.

In a study by Barak et al. (2011), 1335 elementary school students were divided into two groups – experimental and control – to study the effects of animated movies on science thinking skills and motivation to learn science. The students who studied science with the animated movies were scored higher on measures of motivation to learn science and enjoyment of science. Students who learned science with animations also made more connection with daily life than students who studied science with traditional methods such as textbooks pictures. The combined use of the animated movies with classroom discussions and written assignments encouraged students to exchange their ideas verbally in discussion groups and exchange their ideas in written text assessments. Group discussions and group assignments increased students' understanding of science concepts. The use of animated movies helped students to explore new concepts and enhanced their understanding and ability to explain scientific concepts. Furthermore, it was associated with their motivation to learn science 'in terms of self-efficacy, interest and enjoyment in comparison to students who studied science in a traditional way, using only textbooks with still-pictures' (p. 844). This result is also supported by Hübscher-Younger and Narayanan (2007), who claim that animations illustrate complex and dynamic processes for students as well as allowing learners to make daily life connections with their existing knowledge.

Finally, some suggestions derived from the literature about the use of visualisation and animations in teaching and learning will be summarised. Animations are helpful when complicated structures and dynamic process are involved (Dori & Barak 2001; Najjar 1998), especially when verbal explanations are added to visual representations (Kaberman & Dori 2009; Najjar 1998). Animations should be used when they are directly related to the curriculum and have potential to contribute to the learning of the curriculum (Hoffler & Leutner 2007; Mayer, Heiser & Lonn 2001). They should not be used when students can imagine the subject and concretise it independently because it can limit students' imaginations and can be time consuming (Schnotz & Rasch 2005). In addition, students should be encouraged to communicate while learning with animations (Barak et al. 2007; Betrancourt 2005). In short, the use of computer animations has potential as a powerful tool for science lessons when it is used effectively. In the next section, student-generated animations will be explained and discussed.

2.4.1. Student-generated animations

This sub-section will examine animations generated by students to explain science concepts, using examples from the literature. Section 2.4 drew attention to a selection of studies that show the importance of computer-based animations for promoting students' learning in chemistry, but there is limited research into student-generated animations for students' learning of chemistry concepts (Chang & Quintana 2006; Hoban et al. 2009; Hoban & Nielsen 2010; Hoban & Nielsen 2014). Student-generated models or animations are not new ideas (Udo & Etiubon 2011), but there is limited research on animations that focuses on using the social constructivist approach to support students' understanding and learning.

There are different sorts of student-generated animations. Clay animation is one of the most frequently used student-generated animation tools in schools, but it is also time consuming and difficult to use when trying to show the movement of models (Barab, Hay, Barnett & Keating 2000; Chang & Quintana 2006; Schank & Kozma 2002). Moreover, creating an animation with clay has generally been used for the teaching of art or literacy rather than science (Hoban et al. 2009). Another way to construct animations is to use computers as animation tools. As discussed in Section 2.3, animations promote active learning, visualisation of chemical processes, interpretation and reasoning (Papert 1991). As well, the construction of animations helps to make learning more enjoyable, practical, motivational and encouraging (Chang & Quintana 2006). Constructed models can also provide feedback to teachers about students' deep understanding because 'building a model is like thinking aloud' (Stieff et al. 2005, p. 111). They also help students to create, modify and discuss representations (Danish & Enyedy 2007) rather than be unthinking consumers of science and passive learners of scientific representations (diSessa & Sherin 2000; Greeno & Hall 1997).

If clay animation or other time-consuming, student-generated animations are to be avoided, special software programs for student-generated computer animations are needed. In Hoban et al's (2009) study with the Slowmation (abbreviated from 'Slow Animation') software program, elementary school pre-service teachers (N = 29) created their own science animations. After a two-hour workshop, participants created a Slowmation on a chosen topic that had been assigned at the beginning of the course. The study also sought to determine whether their use of Slowmation for their own animations resulted in them using it in their teaching. Data collected from three interviews, two concept maps and created animations were analysed. Changes in scientific knowledge about a topic were identified according to the number of new concepts or insights that were added to their concept maps. A major increase in science knowledge was identified as one adding four or more new concepts or exploring one concept deeply. A minor increase in science knowledge was identified as adding two or three new concepts. Little or no increase was identified as adding one new concept or no change. The results showed that the majority of pre-service elementary teachers (N = 19/29) had a major increase in scientific content knowledge; about one third of pre-service elementary teachers (N = 9/29) had a minor increase; one person had no increase in scientific knowledge; and pre-service teachers (N = 4/13) used the approach in their teaching classes. These data are consistent with the argument that creating animation improves students' content knowledge in learning because students need to understand the concept before they create an animation. This result also supports the view that when students create their own animations, they will learn more effectively through sharing their understanding of a concept (Hoban & Nielsen 2010; Hoban & Nielsen 2014).

Hoban and Nielsen (2010) have also studied the Slowmations made by the pre-service teachers in this research project. An innovative teaching technique '5Rs' (Representation 1: Background; Representation 2: Storyboard; Representation 3: Models; Representation 4: Photographs; Representation 5: Animation) was used to encourage students to make their own animations. The 5Rs was also used at the end of a topic as a summative assessment. Results show that creating animations helped students to learn a science concept because the 5Rs method allows them to think about a science concept in multiple ways. Comparison of students' interviews before and after creating a Slowmation shows the process often improves understanding of a concept. Even so, Hoban and Nielsen (2010) acknowledge their research is insufficient for knowing how constructing representations influences students' learning. They call for further research into 'to better understand how students learn about particular concepts by videoing students over several hours as they create a Slowmation and encourage them to think aloud (p. 37).

Another study of the student-generated animations was conducted by Chang & Quintana (2006). They used Chemation, which allows students to create their own animations about science concepts and evaluate their visualising, interpreting and reasoning skills. The sample for the study included two chemistry teachers and 73 seventh-grade students. Results of the pre- and post-tests showed that student-generated animations, as an instructional aid, have an encouraging effect on the learning environment of middle-school students. The animations were found to support visualisation of dynamic and abstract concepts. The results of this study should encourage designers of software programs to explore the educational value of active animation programs. Thus there is a prima facie case for using animations to support student learning of complex ideas in chemistry

This section of the literature review has analysed just a selection of the many research studies that show how animations have a significant role in science education (Chang & Quintana 2006; Danish & Enyedy 2007; Hoban & Nielsen 2010; Hoban et al. 2009; Olele 2008, cited in Udo & Etiubon 2011). This dissertation will proceed to explore the more specific question: How do student-generated, computer-based animations influence students' learning in chemistry?

2.5. Conclusion

The literature review brings ideas together from Vygotsky's social constructivism, the representation construction approach and use of analogy, and highlights their implications for this research. How they support the theoretical framework of the study will now be summarised in four parts.

1. To have a meaningful learning, students need to engage in the learning process. Taking a social constructivist view suggests that learning should be an active process rather than passive; learners construct their knowledge. The principles of the representational construction approach also suggest that when students are active and create their own representations, their conceptual understanding of science is deepened. Aubusson and Fogwill (2006) assert that understanding in science is also deepened when students are active and build their own analogies.
2. When students identify their current understanding through analogies, representations or animations, teachers can identify particular points where difficulties arise and they might need to challenge and to influence students' ideas. This is an opportunity to students and teachers to interact ways where the teacher uses the ZPD for student learning, and student-generated analogies or representations find a place in the ZPD. Barlex and Carré (1985) argue that, consistent with Vygotsky's ZPD, it is essential that teachers help students to give expression to their own ideas in the learning process. The principles of representational challenge approach are also relevant to this approach.
3. When student-generated animations are used in science classes as learning tools, meaningful learning is enhanced by students explaining and commenting on them using representational mapping. Because students need help in their visual learning especially, student- and self-generated analogies and animations and the representational construction approach will all take place in the ZPD. Students are not always aware of what they should attend to and what they should ignore (Barlex & Carré 1985).
4. Group work is an important consideration in this study. When students work together and discuss in groups rather than work individually, they develop their cognitive strategies and develop their understanding of what they are doing. Learners in groups develop a common understanding about tasks and how to accomplish them. Students discuss with others, share their ideas and socially negotiate, thereby realising there are many ways other than their own to solve problems or to reach a conclusion (Jonassen, Peck & Wilson 1999). Student interaction makes learning easier and helps cognitive development. When students create their animations with their partners in groups, they need to listen to each other and exchange ideas during the process. The representational construction approach aims for group agreement to reach a resolution on generative representations.

How these factors came together to design a student-generated animation class will be presented in Chapter 3.

Chapter 3: Methodology

3.1. Chapter overview

This research explored a representation-creation pedagogy intervention based on an active process of learning with a teaching sequence that included four phases: training in the software program, creating animations, class discussions, and reflective discussion. In this intervention, students first created their own animations to illustrate and explain their views of science concepts and then compared their animations with those of classmates and experts.

This chapter outlines the methodology used in this research. Section 3.2 explains the theoretical and methodological foundations of the research design. Section 3.3 explains the pilot study. Sections 3.4 and 3.5 describe the research design, the participants, and the context of the research. Section 3.6 identifies the interventions that were used in the research. Section 3.7 describes the data collection methods. Section 3.8 explains the types of research data and their trustworthiness Section 3.9 discusses the ethical considerations of the research. Section 3.10 explains the method of reporting, and Section 3.11 provides a summary with key points.

3.2. Theoretical Perspective of Methodology

This study investigates students' learning in chemistry when they create their own animation representations using a software program with the support of their teacher. The research design was underpinned by social constructivism, the representational construction approach and analogical reasoning. In this context, two groups of Turkish Year 11 high school students engaged in animation creating activities. The framework for these activities is articulated in the following sections of this chapter. In this section, the theoretical framework informing the methodology will be presented.

Social Constructivism

In the context of the social constructivist view of learning, creating animations is an active process in which the students interact with each other and their partners in a classroom environment. Students create their animations in a social environment; they exchange their ideas, while at the same time providing support to each other, which guides each person to clarify his or her views of scientific concepts. They learn through their interaction in the group, they elaborate their thinking to their partners, because each group member has a different internalisation of knowledge depending on their previous knowledge (Powell & Kalina 2009). In the methodology of this research, the choice of group work in constructing an animation was influenced by social constructivist theory and Vygotsky's (1962) social cultural theory.

A key feature of Vygotsky's social cultural theory is the role played by a more knowledgeable person (MKO) to help students in a social learning environment. During the animation creation process, the teacher was the supporting MKO who moved between groups of students to enable them in their zones of proximal development (Vygotsky 1962).

Representational Construction Approach

The principles of representation construction include a learning process for teachers and also students. How these principles of the representational construction approach supports the methodology of this research is presented in terms of related principles.

The first principle is 'teaching sequences are based on sequences of representational challenges' (Tytler et al. 2013b, p. 34). This principle is an important framework of the research because students create a new chemical representational animation with the support of their teacher and discuss the animation when making claims about the states of matter. Students are supported during exploration to identify the problematic nature of phenomena. While students are creating their animations, the teacher moves around the class, watches their animations, listens to their discussions and answers some of their questions. The teacher also asks guiding questions during the creating animation process. These elements of the intervention are consistent with the first principle of the representational construction approach (Tytler et al. 2013b).

According to this same principle, 'there is a process of alignment of students constructed and canonical representations' (Tytler et al. 2013b, p. 34). In this study, this alignment takes place in the discussion held during a follow-up lesson. In this discussion lesson, the teacher presents students' generated animations to the whole class and discusses the best features of each animation to develop a new 'ideal animation'. The teacher also shows some expert-generated animations to the whole class and invites students to identify matches and mismatches between the animations the students themselves had generated in comparison with those of experts.

The discussions during the animation creation process also overlap with the second principle of representational construction approach, which is, ‘Representations are explicitly discussed’ (p. 35). According to this principle, the teacher supports students to construct their own representations and scaffolds their learning during class discussions.

Analogical Reasoning

The intervention in this research required the students’ to discuss their own animations about particular science concepts. The pedagogical purpose of having these discussions after producing the animations is to provide a learning environment in which they can show their understanding of the concepts and how they might develop them further using analogical reasoning (Aubusson et al. 2009; Fogwill 2010). The guideline in these discussions is consistent with Treagust et al’s (1998) Focus-Action-Reflection (FAR) guidelines for teaching with analogies and models (See section 2.2.3).

3.3. Research design

The nature of the research questions shaped the research design of the study. It involved both quantitative and qualitative research methods to obtain the participants’ perspective of the teaching/learning experience. An advantage of this mixed method approach is that it has potential to provide ‘a more comprehensive picture of what is being studied’ (McMillan & Schumacher 2006, p. 401). Qualitative data collection included in-depth interviews, observations and video-recordings. The study also drew on quantitative methods to gather evidence of learning outcomes by employing statistical analysis of pre- and post-tests. Thus the nature of data collected in this research is not confined to either qualitative nor quantitative research alone in seeking answers to the research questions (see also Creswell & Plano Clarke 2007; Silverman 2013).

This research has also been informed by case study methodology in that it investigates a bounded system (Stake 2003; Sturman 1994). The research is bounded by location, which is in one of the private colleges in Turkey; by time, as only two months was available to conduct the research in Turkey; and by the curriculum context, namely, states of matter. In this research, the features established the boundaries of the case. The case study method provides a framework to explore the complexity of interdependent activities (Stake 2003). The intervention in this study combined a range of practices drawn from compatible, but different, theoretical frameworks. This produced a teaching sequence for investigation that consisted of interdependent elements including students creating their own animations, teacher guidance and discussions to critique the animations. The aim of this study is to investigate the ways in which student-generated animations contributed to students' learning processes in chemistry and there are multiple sources of data for triangulation purposes: interviews, focus groups, video records and artefacts. Therefore, this research has been informed by case study methodology in the selection of a bounded case for investigation and methods of data collection. This study also was influenced by elements of design-based research, which will explained in the next sub-section.

3.3.1. Designed-based research

Design-based research (Brown 1992; Collins 1992) refers to inter-disciplinary mixed-method research that takes place within authentic settings and involves close cooperation with teachers and students. According to Wang and Hannafin (2005), design-based research (DBR) is

> a systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings, and leading to contextually-sensitive design principles and theories. (p. 6)

According to Confrey (2006), the central idea behind DBR is that such studies ask questions about how to design teaching to improve student learning, selection of tasks, activities and the resources used:

> DBR seeks to document what resources and prior knowledge the student brings to the task, how students and teachers interact, how records and inscriptions are created, how conceptions emerge and change, what resources are used, and how teaching is accomplished over the course of instruction, by studying student work, video records, and classroom assessments. (p. 135)

DBR brings together specific methods and techniques, such as video recordings, discussions and statistical analysis. Because of the need for rich diverse sources of evidence on the designed interventions, DBR data collection methods require large amounts of data (Brown 1992) and the triangulation of multiple source of data, such as interviews, focus groups, video records and artefacts, to ensure generalisable use of designs in other learning settings. For evaluating students' reasoning in DBR, Cobb and Gravemeijer (2008) also recommend methods such as interviews with students and using videos to observe and assess the whole-class performance, rather than traditional paper-based assessment, The aim is not only to track learning outcomes but also to gather evidence on how to design the learning activities such as tasks, materials, interactions and instructional sequences (Reimann 2011).

Cobb & Gravemeijer (2008) describe DBR as 'formulating testable conjectures' (p. 70). The design of classroom norms, tasks and materials, and activities is driven by a central idea (Confrey & Lachance 2000) and gives a mediating role to the teachers in classrooms. Data collection needs to be carefully planned to test the conjectures. It should cover the whole learning process rather than only students' learning and classroom practices (Reimann 2011). Edelson (2002) suggests that the teaching should be video- or audio-recorded and that all recordings be transcribed to provide data sources for investigating the conjectures. In this research, it is conjectured that when students work in groups to create their own animations to represent their conceptions supported by their teacher and discussions to analyse animations, they will develop their understanding of science concepts.

In this research, the central task is creating analogies by using a software animation program and using an intervention in two classes. Different kinds of data were collected, such as classroom discourse, semi-structured interviews, and classroom discussions. The researcher is trying to understand that what is going on in the learning process through the teacher and through the students, as well as through the pre- and post- tests and student work artifacts.

Another common characteristic of DBR is the close involvement of the researcher with the study of the participants. In this research, the researcher designed the proposed teaching sequence and teaching approach in consultation with the teacher. The researcher also gathered the data with the close co-operation with the teacher. The teacher carried out all activities after negotiation with the researcher. Furthermore, as part of the research process, the researcher provided a summary of the findings to the teacher so that she could comment on them. Thus the research was conducted with, rather than on, the teacher and her class.

Although this research draws on DBR the research is not claimed to be DBR. In DBR a series of iterations with progressive improvements in the design of the intervention would be expected (Confrey 2006). In this research, the limited access to the school and the late withdrawal of another school from the research, together with the time required to translate and analyse the large, diverse data set, meant that only modest modifications in the design were possible. These modifications were based on a limited pilot study. Consequently the focus of this research is on the extensive data obtained in what could be considered a single intervention. Future work could involve a series of such intervention.

Considering the methodological elements of this research, as outlined above, it is clear that this research is neither a pure rendition of these elements nor restricted to a single methodology. Rather, it is informed by a range of compatible aspects drawn from appropriate methodologies that are nested within each other. Figure 3.3.1 seeks to provide a representation of this nested methodology.

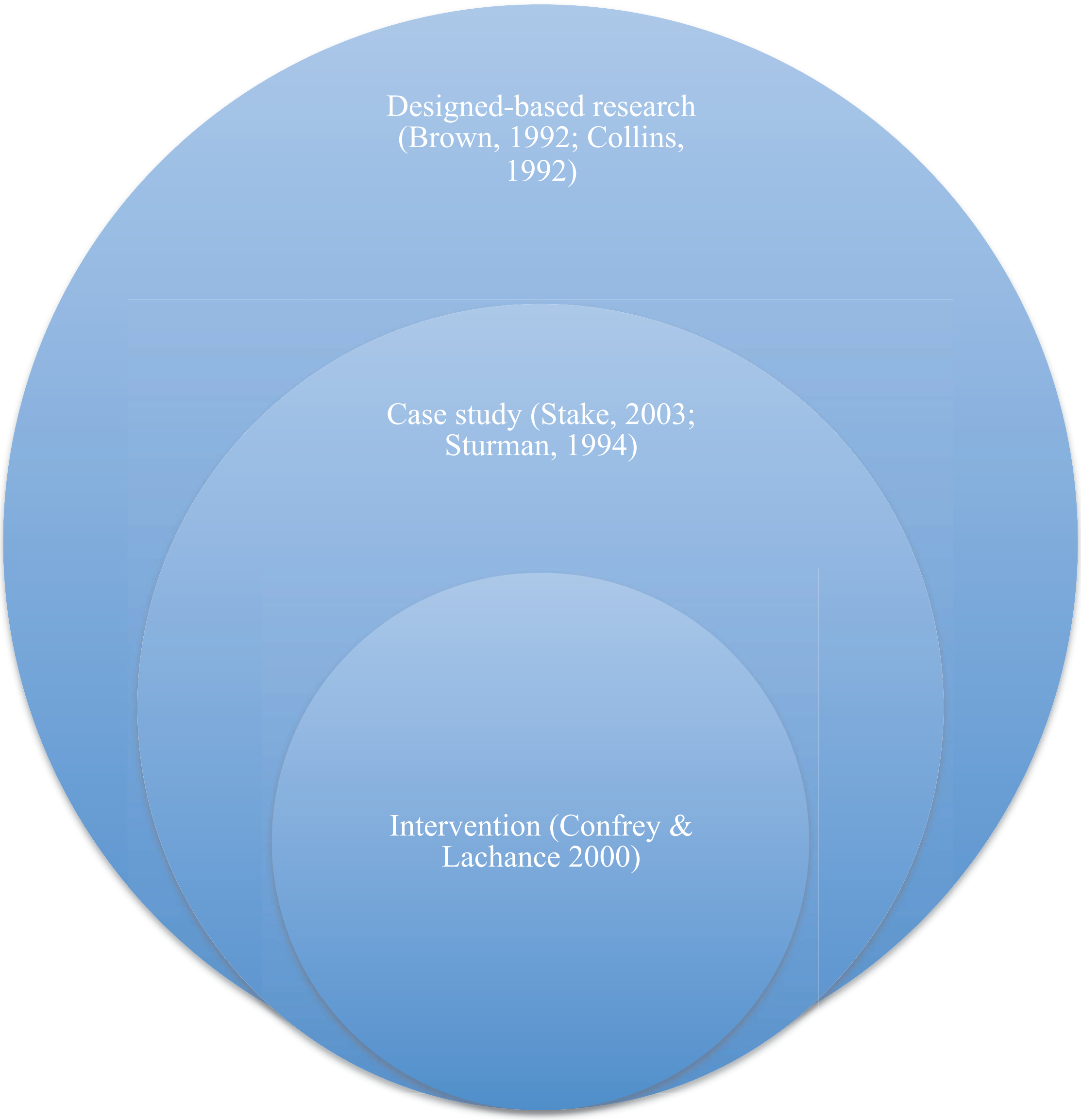

Figure 3.3.1 The methodological position of this research

This research design was guided by the following four questions:

1. In what ways do student-generated animations influence students' conceptual learning?
2. How do interactions among students influence learning when they are creating animations?
3. How do interactions between teachers and students influence learning in the animation creation process?
4. How do analysis and discussions of the animations contribute to students' learning?

Engagement with the first question required identifying students' explanations of states of matters during their creating of the animations with the software program. Students' interviews provided evidence for the effectiveness of the animations. The second and third questions required gathering data and analysis of student–student interactions and teacher–student interactions. The interviews contributed to the analysis of the interactions between student partners and with the teacher. In response to question four, the researcher used the video recordings and interviews of the follow-up class discussions.

3.4. The pilot study

A preparatory pilot study for this research was completed in Australia two months before the research was undertaken in Turkey in 2013. In this period, the researcher undertook the animation creation part of this research. The participants in the pilot study were pre-service science teachers in their science methods class. The purpose of the pilot study was to test whether the affordances of the software and technology permitted students to collaborate in the creation of animations to represent views of kinetic theory of matter. This group selected for the pilot was, in part, a sample of convenience. The participants were considered suitable because it was anticipated that they would already possess sound understandings of the relevant science. Hence, the capability to animate rather than the knowledge of science would be the primary influence on determining whether the proposed software and technology could facilitate the collaborative animation that was sought in this investigation. The researcher first introduced the K-Sketch software animation program to the whole class. After they learned how to create animations in the K-Sketch program, they used it to draw their scientific animations in small groups. They discussed their work with their classmates in the groups and they received guidance from their teacher. For pre-service teachers, the process of learning the K-sketch program and creating group animations took three continuous hours. All groups created animations that facilitated discussion of views of kinetic theory of matter.

This pilot study helped the researcher become familiar with the sequence of steps needed for instructing users of the animation program and provided an opportunity for gain insights into the time frame of the study. It also suggested ways the K-sketch user guide worksheet should be modified. A follow-up discussion which the class was also added to the research design to gaining more clarification about students' ideas and understanding after the representation creation process. Just before the 2013–2014 academic year started in Turkey, the design of the study was approved by the researcher's supervisor. Only small changes were needed for tutorial 4 on the K-sketch animation user guide worksheet (See Appendix 4). Rectangular or square shapes rather round shapes would be drawn so as not with resemble to molecular shape shown in the textbooks.

3.5. Participants and Context of the Study

The research was conducted in two classrooms of a private K–12 college located in East Anatolia Region of Turkey. A second school had originally agreed to participate in the research but unfortunately, after the researcher arrived in Turkey to carry out the research, the school advised that it was withdrawing from the project. The student population in the participating school was homogeneous. The socioeconomic statuses of most students' families were high at this private school, with only a limited number of students eligible for scholarships.

General secondary education in Turkey covers the education of children between 15 and 18. In public high schools students attend six classes each day, which last for approximately 40 minutes each. In private high schools, the daily program is typically longer, up to eight classes each day, also including a lunch period. All 9^{th} graders are taught the same classes nationwide, with minor differences in certain cases. When students enter the 10^{th} grade, they typically choose one of four tracks: Turkish language–mathematics, science, social sciences, and foreign languages. At the end of high school, following the 12^{th} grade, students take a high school finishing examination and they are required to pass this in order to take the University Entrance Exam and continue their studies at a university.

A total of 28 students was chosen to participate in this research. The participants were Year 11 Science students taught by the same teacher in two classes, 11-A and 11-B. The students in the two classes were not graded; they had mixed ability. These students and their teacher signed consent and information forms (Appendix 2b & 3b). Students took pre- and post-tests individually but they created the animations in the K-Sketch program as partners. There were eleven groups in this research – ten groups were pairs and one group had three students. By the end of the study, three students had been removed from the data set because they did not attend the pre-test, and another two were removed because they did not participate in the K-sketch animations sessions. Subsequent to the K-sketch animation sessions, a further four students were removed when they did not take the post-test.

Group 11-A comprised seven females and eight males in seven groups. Group 11-B had four females and four males in four groups. None of the students had previously used the animation program in science classes. All had taken chemistry classes in Year 9 and advanced chemistry classes in Year 10.

The concept the students were learning was states of matter. According to Science Education curriculum in Turkey, students cover the states of matter in Year 4, Year 6, Year 9 and Year 10. In Year 4, the unit mentions the states of matter as solid, liquid and gas, explains the main properties of each phase. In Year 6, the phases of matter and its particles are given. In Year 9, more examples are given to solid, liquid and gas phases, their particular properties are explained in detail. In Year 10, the attraction forces between solid, liquid and gas phase are given.

The teacher who participated in the study had 13 years experience teaching chemistry in various high schools, and had been teaching in this college for three years. The research activities were implemented in six class periods of 40 minutes each. In the first week, this time was used to explain the aim of the study and conduct the pre-test. In the second week the K-Sketch animation program was taught to each class in separate periods. In the third week, the students created their own animations using the K-sketch animation program. In the next period, they had a follow-up discussion class. Students' interviews were completed in the following week with a follow-up discussion class and the post-test was held the following week of interviews. Finally, the teacher was interviewed for an hour. The interventions framework of the study is given in Table 3.5.1.

Table 3.5.1: The Framework of the Interventions

Period	Time	Interventions	Instrument	Analysis Methods
1^{st} week	One class hour, 40	Aim of the study and pre-	ESSA with added drawing	SOLO taxonomy, statistical

	minutes	tests	question	quantitative analysis
2nd week	Two class hours, 80 minutes	Teaching of K-Sketch animation program	K-Sketch software program	
3rd week	One class hour, 40 minutes	Producing science animation	K-Sketch software program Observations Audio and Video recordings	Coding the students' videotaped and audiotaped dialogues with partner and the teacher, qualitative data
	One class hour, 40 minutes	Follow-up discussions	Observations Video recordings Expert animations	Coding the students' videotaped dialogues, qualitative analysis
4th week	10-15 minutes	Student interviews	Semi-structured stimulated recall interview questions Students' K-Sketch animations	Analysis of transcript data, qualitative analysis
5th week	10-15	Post- tests	ESSA with	SOLO

	minutes		added drawing question	taxonomy, statistical quantitative analysis
6^{th} week	1 hour	Teacher interview	Semi-structured interview questions	Analysis of transcript data, qualitative analysis

3.6. The framework of the activities

This research involved interventions designed to explore how students used animations in their science learning. The specific interventions were negotiated with their teacher and took into account the contexts of individual classes. They targeted the development of key concepts about states of matter that were being addressed in the school at the time the research was conducted. They were intended to create a learning environment that allowed student involvement in developing their scientific knowledge about changes of states. The interventions occupied four class periods and consisted of four phases: training in the software program, creating animations, discussions of students' and experts' animations, and reflective discussion.

Phase 1 and Phase 2

The first phase was the training in the software program to create a science animation using the K-sketch animation program. The researcher used an active learning process to teach the program during two class periods. Students used their own laptops and the K-sketch user guide (Appendix 4) to learn how to use the program. When all students completed the four tutorials, it was assumed that they could use the program to create their own science related animations. The K-Sketch user guide included the following four tutorials:

- Tutorial 1: Count Down, which taught how to give motion to basic subsequent drawings.

- Tutorial 2: The Car Jumped Over the Plane, which showed how two different objects could move at the same time.
- Tutorial 3: Rolling Down which provided information about how to copy the movement.
- Tutorial 4: Disappearing of Small Shapes, which combined the first three tutorials

In the following week, Phase 2, the students attempted to create science-related animations using the K-sketch animation program with their partners. They were asked to draw the three states of matter: solid, liquid and gas. In particular, they were asked to imagine that they could see into the matter with an impossibly powerful microscope to see what matter was made up of and what it was doing. They were then asked to 'draw what they imagine'.

In the first stage of the process, the students tried to create their animations with their partners by using the key concepts of matter, with the teacher as MKO scaffolding their learning. The researcher discussed with the teacher what she wants to do and how she could do it. This was to ensure that much as possible the teacher was aware of the steps that would be done during the process. Students actively designed their representations to explore states of matter while the teacher raised relevant aspects of representations of matter with students for them to consider in their animations, such as vibration, the distribution of molecules and the motion of molecules. Before the canonical forms were given, the teacher supported them to organise and improve their representations. Canonical forms were not given during the creation of the animations. Figures 3.6.1 and 3.6.2 show both classes while they were creating the animations.

Figure 3.6.1: 11-A Creating animations

Figure 3.6.2: 11-B Creating animations

Phase 3 and Phase 4

After the students had created their animations, there were follow-up discussion lessons for class sections 11-A & 11-B. This was Phase 3. In each class section, the teacher followed the same stages. In the first stage, the students elaborated on their own group's animations. The teacher showed each group's animation to the whole class by projecting it onto the class board so that the whole class could watch it. The members of each group then explained their animations to the whole class.

In the second stage, the teacher invited students to comment on and critique others' animations, and to ask questions about anything they thought was unclear in the animation or were inconsistent with their own ideas.

In the third stage, after each group's animation had been shown and the discussion completed, the students watched expert animations created in the K-sketch and in other software programs. All these expert animations were visualising the states of matter.

In stage four, the teacher led a discussion that provided an opportunity for students to think more about the changes of state and to see the similarities and differences between their animations and the expert animations.

After the last stage in Phase 3, in Phase 4 the teacher led a reflective discussion on the learning process. The students critiqued the teaching and learning process from the beginning, when they had learned how to use K-Sketch, to the end of the teaching process, when they discussed their own and the expert animations. They also evaluated the Phase 3 discussions.

3.7. Data collection and recording procedures

The data were collected during school time in October and November 2013. The research was implemented in six class periods, each of 40 minutes, in both classes 11-A and 11-B. The researcher was planning the lessons and the teacher used it as a professional learning experience. The researcher taught the software program to students and set up recording settings before each class period. The teacher carried out all activities after negotiation with the researcher. The researcher is trying to understand that what is going on in the learning process through the teacher and through the students. After completing the interventions, the researcher administered the post-tests to both groups of participants and interviewed all the groups and the teacher. The researcher also provided a summary of the research process so that students comment to the whole process and evaluate it.

As outlined in Section 1.8, both qualitative and quantitative methods were incorporated into the research methodology. The data sources included the Essential Secondary Science Assessment (ESSA) extract questionnaire (pre- and post- tests), the K-Sketch animations produced by students, videotaped and audiotaped recordings of students interactions during animation creating process, and interviews of students and teacher. The analysis was mainly interpretive (Harrison & Treagust 2001) because of the nature of the research questions and the visual nature of animations. Quantitative data were also used to explore possible changes of students' understanding with descriptive analysis (McMillan & Schumacher 2006). The following sections describe each data source.

Questionnaire ESSA extract as pre- and post-test: A questionnaire (Appendix 5) was developed that requested students to answer seven questions. Students completed the questionnaire before the whole process as pre-tests. Post-tests were completed a week after the creation of the animations and interviews, both of which took place in the same day. The questionnaire included open-ended questions and multiple-choice answers that allowed for students' explanations and visualisations of the 'states of matter' concept. Students also answered the questions by drawing and explaining their drawings.

Essential Secondary Science Assessment (ESSA) questions were chosen as pre- and post- tests. ESSA is a science assessment program in NSW, Australia. It is based on the Years 7–10 science syllabus. It helps students 'to see the relevance of science and to make meaning of scientific knowledge, understanding, skills, values and attitudes' (NSW Public Schools 2014). This test was chosen for the pre- and post- tests because it subjected student respondents to extensive expert scrutiny and analysis. In addition, it is hard to assess the extended open questions without them being based on reliable and confidential assessment criteria. In ESSA, experts are assessing the students' answers using the SOLO (Structure of the Observed Learning Outcome) model over years. SOLO taxonomy is a recognisable progression in literature (Biggs 1995). Therefore, it helps the researcher to identify features of student responses as described in the marking guidelines (Appendix 8) and apply the marking accurately and consistently.

Six questions about assessing student understanding of particular theory of matter were taken from the ESSA test. These questions were translated from English to Turkish. Students were asked to choose the correct answer from multiple-choice questions concerning science experiments, including some about heating ice. Some questions required box ticking and others a written response. The researcher created the final question to invite students to use their imaginations to explain the ice-heating experiment. In this last question, students drew the molecules as temperature changes, rather than explaining in words (see Section 4.2.5). Taken together the answers to these questions provided information about the students' scientific knowledge about states of matter both before and after the students' animation creating process.

K-Sketch animations: The *K-sketch* software program (http://www.k-sketch.org/) was used by students to construct the animations in the students' representation creation process. The program was designed to create basic animations from sketches. It is a free drawing and design program rather than a science-tools program. An intention of this research was to see if this software could be used as a visual scaffolding tool to help students to understand the molecular world and to make links between what they can see and not see in chemistry.

The *K-sketch* animation program was taught to students during two lesson periods, following which they designed their own animations in small groups. Students used the K-sketch animation guide (Appendix 4). All students created three non-science related animations, one in each tutorial, during the two lesson periods. It was presumed that the students had then learned the program sufficiently well to create their own animations using K-sketch software program.

Videotaped and audiotaped recordings: Conversations between the teacher and students and interactions among the students were videotaped during the students' animation creating process. Classes 11-A and 11-B were video recorded as they were learning the K-Sketch animation program, creating their own animations on that program, and in the follow-up discussion classes. To record these activities in the classroom at the same time, the researcher set up one camera at the front of the room and another at the back of the room. As well, in each of the two groups a volunteer used a close-focus camera to record conversations. The researcher also had a camera in her hand to record conversations as she walked among groups while they created the animations. The students' interviews and the teacher interview were transcribed from audiotaped recordings.

Interviews: Semi-structured, stimulated recall interviews (McMillan & Schumacher 2006; Slough 2001) were held with all student groups and also with the teacher. The students were interviewed after the follow-up discussion class. The aim of interviewing was to gain the students' insights about the concept that were studied and the effectiveness of whole animation creating process. It was also to find out what the students said they were thinking or feeling about while they were doing the animation task. In the follow-up discussion class they watched their own animations with the researcher. The researcher stopped the animation at some points and asked the students questions related to the animations. She also asked the groups about teacher support, partner interaction and the follow-up discussion class, and for their overall ideas about the whole process (Appendix 7). Interviews with each student group took about 15-20 minutes, with each interview session audiotaped and transcribed. In addition, the researcher interviewed the teacher for about an hour to ask about the advantages, and disadvantages of using student-generated animations in science classes. She also talked about each group's animations in both Class 11-A and 11-B when watching them again during interview session. The teacher's interview session was also audiotaped and transcribed. All the data recordings and transcriptions were in Turkish and then translated into English by researcher.

3.8. Analysis

This section describes how the data were analysed. All the verbal data were obtained and transcribed in Turkish then translated into English. The data analysis of this mixed-method study included two distinct parts, the qualitative and the quantitative components. Qualitative methods were used to understand why students did or did not perform better on these tests and how the interventions affected students' learning. The particular type of analysis required for pre- and post- tests involved quantitative methods.

3.8.1. Qualitative analysis

Qualitative analysis was used so that participants' perspectives and actions could be examined in depth in natural situations. An interpretivist epistemology was used to seek understanding of student perceptions about their animations through interviews and observations (Angen 2000; Creswell 2003; Mackenzie & Knipe 2006). This followed the general process of inductive data analysis outlined by McMillan and Schumacher (2006, pp. 364–377), including establishing text extracts from interview transcripts, identifying patterns (themes and key concepts), coding and categorisation.

From the data collected, the key points were marked with a series of codes that were extracted from the text. The codes were grouped into similar concepts in order to make them more manageable (McMillan & Schumacher 2006). New codes were included as they emerged from the data. Data analysis started with coding the students' videotaped and audiotaped dialogues. In this coding process, the researcher used the transcribed student–student (partner) and teacher–student interactions during the animation creation process.

Student–student interaction categories were included as they emerged from the data. The researcher first divided them into seven categories. A university professor in science education checked these seven categories and suggested that two were similar to each other. These were then combined with other two categories. In the next stage, the student–student interactions were divided into five categories and at least one example from the extracts was added into those five categories. The researcher explained each example in each category.

Categorisation of teacher–student interactions was also shaped in the same way as the student–student interactions. The researcher first created categories from the teacher–student interactions. The same university professor then checked all categories and translated examples of categories from the video and audio recordings to confirm that the categories covered all the different kinds of interactions. Teacher–student interactions were divided into seven categories and at least one example was added to all seven categories. Explanations and examples are given in the analysis section of Chapter 4.

For both Classes 11-A and 11-B, the follow-up discussion classes were analysed with reference to the Representational Construction Approach Principles Analysing Sheet (Appendix 7). Table 3.8.1 shows Class 11-B's first three minutes and 27 seconds in the follow-up discussion class coded against the representational construction approach Principles. This table helps describe the follow-up discussion class according to representational construction approach and it shows which elements of it were evident in the follow-up discussion class.

The first two columns of this sheet show the passage of time in the follow-up class. The third column presents the representational construction code and the fourth column specifies the representational construction approach principle (see Section 2.2.2). The fifth column gives details about the principles. Column 6 presents teacher's quotes and column 7 the students' quotes.

Table 3.8.1: RCA Principles Analysing Sheet for Class 11-B

Time start	Time end	Rep. Const. Code	Principle	Details	Teacher Quotes	Student Quotes
0:39	0:48	1a	Planning-overview	Set up the lesson format and aim of lesson is defined	We will create an ideal animation in our minds with our teacher.	
0:49	0:52	1a	Planning-resources	Explaining which resources will be used	Firstly, we will show each group's animation to whole class.	
0:52	0:56	1a	Planning-format	Instructions	Then you will make comments about each pair's animation and your teacher will guide you.	
1:55	2:08	2ab	Multiple representations, group representation	Representation are shown on the board	Let's watch S9 and S6's animation	
2:09	2:11	1b	Exploration-teacher instruction	Teacher calls class to discuss about animation	How this animation looking?	
2:11	2:13	1b	Student interaction	S5 explain his ideas to class		S5: It looks very good.
2:13	2:19	1c 2bd	Representation construction-teacher student interaction	Teacher supports students to critique their friends' animation	1. What is very good? Which part you like more? Why you are thinking that this animation is	2. S5: Could you restart the animation please?

					good S5?	
2:20	2:32	1c 2bd	Representation construction- teacher student interaction	Teacher tries to encourage to make critique with other students	1. What happened S7? which part you like?	2. S7: from solid to gas the arrangement of particles changed clearly
2:33	2:43	1b	Representation construction- teacher instruction	Students are supported before canonical forms. Teacher critique representation	From the solid state to gas state they are well-separated and no regular arrangement. in the gas state volume increases because no regular arrangement.	
2:44	3:10	1c 2bd	Representation construction- teacher student interaction	Teacher calls class to discussion	1. Do you think that is this animation ideal? Is this animation ok? How can we improve this animation? What can add to or change in this animation to improve it?	2. S7: transitions should be changed. 3. S9: Instead of sudden shift from right side to left side to show solid to gas, it should be appear straight on the left.

3:11	3:27	1b	Represen tation constructi on- student interactio n	Students are asking questions to other students (whom they created the animation) to really understand the animation		1. S4: Actually I don't understa nd this last moveme nt? 2. S7: yes what is this? 3. S9: this is gas. It is becomin g gas 4. S6: They are moving faster their energy is increasin g and they are evaporati ng and their regular particle arrangem ent is decreasin g from liquid to gas.

The video recordings in the follow-up classes were also transcribed. The student–student and teacher-led discussions for each group's animations were explained in the data analysis chapter (see Section 4.3). In addition, screen shots of each group's animations using the K-sketch animation program were added to the appropriate transcriptions while students' animations explained detailed in Section 4.4.2.

3.8.1.1 Trustworthiness

In this section the trustworthiness of the qualitative research will be considered. According to Lincoln and Guba (1985), the trustworthiness of qualitative data is important for convincing the reader that research findings are credible. To establish the trustworthiness of the qualitative data used in this research, the researcher used the following strategies: member checking, prolonged engagement, triangulation, peer debriefing, and inter-rater reliability. Each of these strategies is explained below.

Member checking

Member checking was used to confirm and further examine the students' conceptual understanding of the states of matter. In a simulated video interview, all the students, discussed both on and off screen what was happening while they were creating their animations and in the follow-up discussion classes. They also discussed whether or not the researcher's interpretation about their animations correlated with what they had drawn using the K-sketch animation program.

Prolonged engagement

To establish a prolonged engagement, the researcher attended classes two weeks before the intervention activities started. During this two-week period the researcher introduced herself and became familiar with the students, the teacher and the research site. During the four-week period when the instructional activities were implemented, the researcher attended both Classes 11-A and 11-B to videotape the interactions, monitor the classroom environments and observe the participants as they engaged in their activities.

Triangulation

Triangulation in qualitative research involves using multiple data sources to test the validity of the study. According to Burns (1994), it is 'the use of two or more methods of data collection in the study of some aspect of human behaviour' (p. 272). Denzin (1978) and Patton (2002) have identified the following four types of triangulation: methods triangulation, triangulation of sources, analyst triangulation and theory/perspective triangulation. Methods triangulation is suited for the data gathering in this research because a wide range of data was collected from multiple methods and sources. These methods include pre- and post-tests, K-sketch animations, expert animations, follow-up discussions, partner interactions, audio and video recordings, student interviews, and a teacher interview. This large amount of qualitative data was collected to establish strong validity for the findings from this study.

Peer debriefing

According to Lincoln and Guba (1985), peer debriefing is 'process of exposing oneself to a disinterested peer in a manner paralleling an analytic session and for the purpose of exploring aspects of the inquiry that might otherwise remain only implicit within the inquirer's mind' (p. 308). Peer debriefing contributed significantly to the review and assessment of transcripts and to the categories emerging from the transcripts. Videotaped classroom observations, transcribed interviews, and the animations were included in the peer review. The researcher's academic supervisor supported its progress by giving feedback after the pilot study, helping to organise the data gathered, watching the intervention activities, and helping to design the methodological procedures. The researcher also presented data in two seminars and invited comments and feedback from the audience on data samples and their analyses.

Transferability

Transferability refers to how the findings of qualitative research can be applied or transferred to other similar contexts or settings (Lincoln & Guba 1985). While not necessarily involving big claims, it calls readers to make connections between elements of the research and their own experiences. This research supports transferability with rich descriptions of the context and experiences of students with the animation creation process. These descriptions allow the reader to determine relevance to other contexts or time frames.

This research provides a measure of validation for the theoretical frameworks (representational construction approach and analogical mapping) because it gives examples of the use of instructional approaches in teaching. As well, because the teacher was aware that the K-Sketch animation program is new to her teaching, she willingly learned how to use it in order to apply elements of the representational construction approach and analogical mapping to her other classes at various levels. Similarly, teachers at middle schools or high schools might selectively apply the results of this research to their own classrooms.

Inter-rater reliability

Twenty-five per cent of students' responses on the pre- and post-tests were selected in a systematic random sampling. The researcher made a list of all students and selected each fourth participant on the list. The researcher and a university researcher who had training in ESSA marked the selected students' answers in the pre- and post-tests. The agreement between students' responses to the extended open-ended questions was first calculated as 85%. When disagreement occurred in the assessment, it was discussed in detail and full agreement was reached between both scorers. The academic supervisor of this research (a professor in science education) checked the coding of selected interview transcript translations and the follow-up discussion transcript translations of the student–student and teacher–student interactions. This then allowed agreement to be reached between the researcher's categories and the supervisor's recommendations prior to completing the analysis of all transcript data.

3.8.2. Quantitative analysis

Students' responses to questions in the ESSA Questionnaire (see Section 1.6) on pre- and post-tests were analysed as numerical data. The multiple-choice questions were coded as Q1.1, Q1.2, Q1.3 and Q1.4. For Q1.1 and Q1.2. Standard ESSA item-scoring processes were employed (Appendix 8). Students scored 1 point for a correct answer and scored zero for an incorrect answer. For Q1.3 and Q1.4, students scored 0, 1 and 2 points. When the students ticked one of the four boxes with the correct answer, they scored one point. When they ticked two of the four boxes with the correct answers, they scored 2 points. When they ticked any of the four boxes incorrectly, they scored zero.

Open-ended questions in the ESSA Questionnaire were coded Q2.1 and Q2.3. They were scored according to the SOLO taxonomy levels used in the ESSA marking. Students' responses for both pre- and post-tests were analysed in each of six levels in the marking rubric (Appendix 8). In addition, Question 2.2 in the ESSA Questionnaire (see Section 1.6) included the students' drawings, which were categorised according to 'The Particle Theory of Matter: The Kinetic Molecular Theory'. A detailed explanation of the analysis according to The Kinetic Molecular theory is given in the next chapter (Section 4.2.3).

Nonparametric statistics were used to analyse the numerical data. The Wilcoxon signed-rank test was selected for evaluating the students answers both prior to and following the students' representation creation process in terms of understanding the key aspects of states of matter. The Wilcoxon signed-rank test was employed to identify any statistically significant difference between pre- and post-test results of students' responses in the ESSA Questionnaire (see Section 1.6). The results were then statistically analysed in the paired sample t-test and the p-value was calculated to test for a statistically significant difference between students' pre- and post-test results for multiple-choice answers and for their drawings. For the descriptive analysis, the sum of the students' tests scores and mean values were reported. In addition, for the descriptive analysis of Q2.1 and Q2.3, Inter Quartile Range (IQR) was also reported and used to measure the spread of the data points in the data set. It shows the complete picture of the data set's tendency based on pre- and post-test results.

3.8.2.1 Validity issues of the research

This section considers the validity of the quantitative research component of this study. It describes the ways in which some specific threats to internal and external validity were controlled.

Internal validity

In the context of the internal validity, history can be 'extraneous incidents or events affecting the results that occur during the research' (McMillan and Schumacher 2006, p. 136). In this study, there were no known external events that might affect the students' performance on creating animations. Each group completed its animations in one class hour and had a follow-up discussion class the same day.

Selection could be a threat if there was a systematic difference between the groups (McMillan & Schumacher 2006). Even though students were not randomly assigned to groups in this study, the school principal confirmed that students were assigned to each class randomly in the beginning of the semester.

Pre-testing itself might have an effect on the subjects; they might perform better due to practicing and familiarising themselves with the test (Best & Kahn 1993). In this study, students took the post-test six weeks after taking the pre-test. Therefore, the length of the time between tests was particularly long and likely to decrease the potential effects of students' familiarity with the questions.

Maturation refers to 'changes in the subjects of a study over time that affect the dependent variable' (McMillan & Schumacher 2006, p. 138). For example, it is possible subjects may become older or wiser between pre- and post-tests. During the six week period between this study's tests, there was little likelihood that maturation could affect results. In addition, becoming bored, feeling hungry or tired can be a threat to internal validity (McMillan & Schumacher 2006). Again this was unlikely because the research instrument took about 10 minutes to complete and there were always breaks after 40 minutes during the animation creating process.

External validity

External validity relates to the generalisability of the results. There are two general categories: population external validity and ecological external validity (McMillan & Schumacher 2006).

Population external validity takes into account that 'the subjects used in an investigation have certain characteristics and can be described with respect to such variables such as age, race, sex and ability' (McMillan & Schumacher 2006, p. 141). Therefore, a researcher should be careful in generalising from data obtained in a research setting and in applying the findings to the other learning settings. This study was implemented in one school in Turkey with one teacher and with high school students; it could not be generalised for elementary schools students, for example. Generalisability of the data is therefore limited.

Ecological external validity refers to 'the conditions of the research and the extent to which generalising the results is limited to similar conditions' (McMillan & Schumacher 2006, p. 141). The factors could be the nature of the dependent and independent variables or environment, physical conditions, timing or pre- and post-test sensitisation. Another factor to take into account is the Hawthorne effect, which is the tendency for people to behave differently when they are aware of being observed (McCarney et al. 2007). In this study, students were informed that they were subjects in a research study, and they may have been more active than usual and excited to be involved. This could affect the findings of the research when compared with other learning contexts. The extended period of the researcher's presence in the classroom was intended to reduce effects arising from the novelty of being observed but the variation from the normal classroom experience arising from the presence of a researcher is undeniable.

3.9. Ethics

Formal ethics approval to conduct this research was required (Appendix 1). This was granted by the Human Research Ethics Committee of the University of Technology Sydney (UTS). Careful consideration of research protocols helped to ensure ethical conduct of the research and to avoid inconvenient situations that can arise during interviews. The research required overseas travel, which includes risk, but travel concerns were addressed by following normal practices for safety during travel including completion of appropriate UTS forms and getting approvals as required.

Information letters (Appendix 3a & 3b) were prepared by the researcher to inform the students and the teacher about the aim, involvement, and risks of the research. It was given to participants at the beginning of the research.

The consent forms (Appendix 2a & 2b) provided to school staff and students described in brief what the research was about. This was prepared so that all the students and teacher could confirm their consent to participate in the research. The forms asked for approval of the students' participation in the research process (including learning the software program, follow-up discussion classes, interviews); collection of data (pre- and post-tests, animations); the use of data for any publications, reports or presentations; and required each student's signature. Confidentiality and anonymous reporting were assured. All participants signed the consent form in all subsequent documentation. The teacher or researcher provided support to students who showed signs of discomfort when using the animation program or during the interviews. The consent form was also given at the beginning of the research.

The magnitude of potential risk in this research was negligible because the research was limited to perceptions regarding the impact of student-generated animation programs on learning rather than collection of personal data. The research process should not have had any negative effects on individual students or groups. It is conceivable that some students experienced minor discomfort during the discussion of creating animations as a pair and during interviews. However, the teacher was in the classroom to support them and manage possible risks. Furthermore, such risks would not differ from those of normal classroom practices when students work in small groups. As well, the teacher reported that she felt comfortable when she was supporting her students and throughout the research.

The security of data is ensured with hard copies in locked cabinets and digital records on a password-protected computer and server, with access only available to the researcher and academic supervisor. Pseudonyms have been used for participants and identifying information has been removed to safeguard the confidentiality/privacy of participants. The name of school has not been reported in the research. The data have been de-identified and the codes stored separately.

3.10. Reporting the study

The aim of this research is to learn how student-generated animations contribute to students' learning processes in chemistry. To reiterate, the research investigates the following four questions in addressing this aim.

1. In what ways do student-generated animations influence students' conceptual learning?
2. How do interactions among students influence learning when they are creating animations?
3. How do interactions between teachers and students influence learning in the animation creation process?
4. How do analysis and discussions of animations contribute to students' learning?

To address these questions, the research design included student-generated animation creation processes, follow-up discussions and interviews. The research investigated what was happening during the interventions, how students' interactions affect their learning, and how a teacher guided students' learning while they were creating their own animations as well as when students presented their animation to the class, discussed and critiqued each others' animations. The data and findings from this research are reported in Chapter 4.

3.11. Conclusion

The interventions developed for this research brought together theoretical perspectives from sociocultural theory, the representational construction approach and analogical reasoning (see Section 2.2).

This investigation of the students' animation creation processes was carried out in an authentic classroom setting. Issues of trustworthiness have been addressed by considering factors that affect the reliability and validity of the research. Elements of student-generated representations, student and teacher interactions, classroom negotiations, teacher support and the use of technology were brought together in designing this research in order to investigate science learning and teaching through animation.

The research design involved a range of qualitative and quantitative methods of data collection and analysis. The qualitative data came from student–student interactions, teacher–student interactions, interviews, students' representations, and video and audio recordings. The quantitative data came from pre- and post-tests and the categorisation of students' drawings according to kinetic molecular theory. Data analysis involved identifying categories, clustering similar data, and triangulating with different data sources and collection methods. The nature of the research questions shaped the design of this research and the analysis of these data addressed the research questions.

The next chapter (Chapter 4), begins the data analysis by presenting data from the students' representation creation process. Findings from this data will be further discussed in Chapter 5.

Chapter 4: Data Analysis

4.1. Chapter overview

As discussed in Chapter 3, this study used a wide range of data to investigate how students creating their science animations and learning processes associated with a teaching intervention. Students completed pre- and post-tests. They were observed, audiotaped and videotaped during the animation-creating process and in the discussion classes. Finally, the researcher interviewed all the students and their teacher about the teaching/learning process.

The intervention was applied twice in each of two classes. To answer the broader research question about how student-generated animations contribute to students' science learning, the data analysis sought answers to the following four sub-questions:

1. In what ways do student-generated animations influence students' conceptual learning?
2. How do interactions among students influence learning when they are creating animations?
3. How do interactions between teachers and students influence learning in the animation creation process?
4. How do analysis and discussions of animations contribute to students' learning?

These four questions focus attention on four corresponding sub-categories: creating animations, student–student interactions, student–teacher interactions and follow-up discussion classes. The whole teaching/learning process is a combination of these four sub-categories. The findings specific to each sub-question are presented in sections 4.4 and 4.5. These findings are the basis of discussion in Chapter 5. Pre-tests were applied before the whole process, and interviews were completed before the post-tests. This chapter presents the data for each sub-question and the statistical analysis of pre- and post-test results. It begins with a discussion of the pre- and post-test results.

4.2. Pre- and post-test results

There were four parts to this study. First, students completed pre-tests about states of matter before the animation creation process. Second, students had an intervention to explore how students use their animations in their learning of science. This intervention consisted of four phases: In Phase 1 they learned the K-Sketch software program; in Phase 2 they created their own animations of the same scientific concept with their partners; in Phase 3 they had follow-up discussion classes about their own animations, their classmates' animations and the expert animations; and in Phase 4 they had a reflective discussion about the whole learning process. Third, the researcher interviewed all the students and their teacher about the teaching/learning process. Fourth, all students completed post-tests after their interviews. This section presents the statistical data for pre- and post-tests results.

4.2.1. Questionnaire

A pre/post-test (Appendix 5) was developed that requested students to answer seven questions. Six of these questions were taken from the Essential Secondary Science Assessment (ESSA) test (NSW Public Schools 2014). Students were asked to choose the correct answers from multiple-choice questions on the first page of the test. Questions 1 and 2 included only one right answer to be chosen from four alternatives. For questions 3 and 4, indicating the correct answers required them to tick two of the four alternatives. They scored one point for each correct answer and zero for each wrong answer. On the second page of the test, there was a diagram showing the heating of ice in an experiment with three open-ended questions about it. The marking of the test questions used the scoring system developed for the ESSA test items. The second question on the second page of the questionnaire was not included in ESSA; it was developed by the researcher. The answers to these questions provided information about the students' scientific knowledge about states of matter and perceptions of the usefulness of the students' animation-creating process. Students completed the test before the whole process as pre-tests. Post-tests were completed two weeks after the teaching intervention and one week after the interviews.

4.2.2. Analysis of Questions 1.1, 1.2, 1.3 and 1.4

Statistical analysis was used to compare students' pre- and post-test results. Table 4.2.1 shows the statistical data for questions on the first page. These questions were coded as Q1.1, Q1.2, Q1.3 and Q1.4. For Q1.1 and Q1.2, students scored 1 point for a right answer and scored zero a wrong answer. The average scores of students in pre- and post- tests were .55points (SD = .510) and .91 (SD = .294) for Q1.1 (Table 4.2.1). The total of the students' scores in the pre-test was 12 and in the post-test it was 20. In other words, while 54.5% students chose the right answer for question one in the pre-test, 91% students chose the right answer in the post-test for the same question. In addition, a Wilcoxon signed-rank test (Table 4.2.2) was used to compare pre- and post-test scores of students for Q1.1. The p-value was found as .011 (<.05), the results indicate that there was a statistically significant difference between students' pre- and post-test results for Q1.1.

Table 4.2.1 shows that the average scores of students in pre- and post-tests were .32 points (SD = .477) and .41 (SD = .503) for Q1.2 and the sum of the scores in pre-test was 7, and in the post-test it was 9. In other words, seven students chose the right answer to Q1.2 in the pre-test and nine students chose the right answer in the post-test. When these results were statistically analysed in the paired sample t-test (Table 4.2.3), the results indicated that p-value is .157 (>.05), so there was not a statistically significant difference between students' pre- and post-test results for Q1.2. In addition to Wilcoxon signed-rank, a paired sample t-test was appropriate for binary data coded 0, 1, but not for other ordinal/nominal data. This test results also show that there was a statistically difference between students' pre and post test results for Q1.1 and there was not a statistically significant difference between students' pre- and post-test results for Q1.2.

Table 4.2.1 also shows the statistical analyses for Q1.3 and Q1.4. Both questions were scored 0, 1 and 2 points. When the students ticked one of the four boxes with the correct answer, they scored one point. When they ticked two of the four boxes on the right answer, they were scored 2 points. When they ticked any of four boxes incorrectly, they scored zero. The average scores of students in pre- and post-tests were .95 points (SD = .375) and 1.09 (SD = .526) for Q1.3. The average scores of students in pre- and post-tests were 1.09 points (SD = .426) and 1.09 (SD = .294) for Q1.4. Questions Q1.3 and Q1.4 were analysed using the Wilcoxon signed-rank test to compare pre- and post-test scores from the same students. Table 4.2.2 shows the Wilcoxon signed-rank test results for pre- and post-tests for Q1.3 and Q1.4. These results show p-values are .317 and 1.000 (> .05) for Q1.3 and Q1.4. This could be interpreted as an insignificant difference between the students' test results before and after their representational creation process.

Table 4.2.1 Questions 1.1, 1.2, 1.3 and 1.4 Descriptive Statistics

	N	Minimum	Maximum	Sum	Mean	Std. Deviation
Q1.1	22	0	1	12	.55	.510
Q1.1 A	22	0	1	20	.91	.294
Q1.2	22	0	1	7	.32	.477
Q1.2 A	22	0	1	9	.41	.503
Q1.3	22	0	2	21	.95	.375
Q1.3 A	22	0	2	24	1.09	.526
Q1.4	22	0	2	24	1.09	.426
Q1.4 A	22	1	2	24	1.09	.294
Valid N (listwise)	22					

Table 4.2.2 Questions 1.1, 1.2, 1.3 and 1.4 Wilcoxon Signed-Rank Test

	Q1.1 A - Q1.1	Q1.2 A - Q1.2	Q1.3 A - Q1.3	Q1.4 A - Q1.4
Z	-2.530[b]	-1.414[b]	-1.000[b]	.000[c]
Asymp. Sig. (2-tailed)	.011	.157	.317	1.000
a. Wilcoxon Signed-Rank Test				
b. Based on negative ranks.				
c. The sum of negative ranks equals the sum of positive ranks.				

Table 4.2.3 Questions 1.1 and 1.2 Paired Samples Test									
		Paired Differences					T	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Q1.1 – Q1.1 A	-.364	.581	.124	-.621	-.106	-2.935	21	.008
Pair 2	Q1.2 – Q1.2 A	-.091	.294	.063	-.221	.040	-1.449	21	.162

4.2.3. Analyses of Questions 2.1 and 2.3

Questions on the second page of the test were coded as Q2.1, Q2.2 and Q2.3. Students were asked to write explanations for these questions, which required them to express their understanding of scientific concepts or principles. They were scored according to SOLO taxonomy levels that were used in the ESSA marking. Students' responses for both pre- and post-tests were assessed in each of six levels in the marking rubric (Appendix 8) by the researcher and an expert in ESSA assessment processes. The Wilcoxon signed-rank test results (Table 4.2.4) p-value was .001 (<.05) and shows there was a statistically significant difference between students' pre- and post-test results for Q2.1 and Q2.3. For the descriptive analysis of Q2.1 and Q2.3, the Inter Quartile Range (IQR) was also obtained and reported (Figure 4.2.1). The IQR was used to measure the spread of data points in the data set. It shows the data set's tendency. Figure 4.2.1 shows the difference between IQR of the pre- and post-tests. The IQR was 3 in the pre-test results and 2 was in the post-test results. While the 95% confidence interval for mean was 2.06 in lower bound and 3.42 in upper bound, it increased to 3.38 and 4.45 for post-test results. While the median was 3 in the post-test results, it increased in the interquartile range to 4 for the post-test results. This increase for IQR was also illustrated in Figure 4.2.1, which shows the statistical difference between pre- and post-tests results for the open-ended questions Q2.1 and Q2.3. This indicates a significant improvement in student understanding of states of matter from pre to post the intervention.

Table 4.2.4 Questions 2.1 and 2.3 Wilcoxon Signed-Rank Test

	SOLO taxonomy A - SOLO taxonomy
Z	-3.331^{b}
Asymp. Sig. (2-tailed)	.001
a. Wilcoxon Signed-Rank Test	
b. Based on negative ranks.	

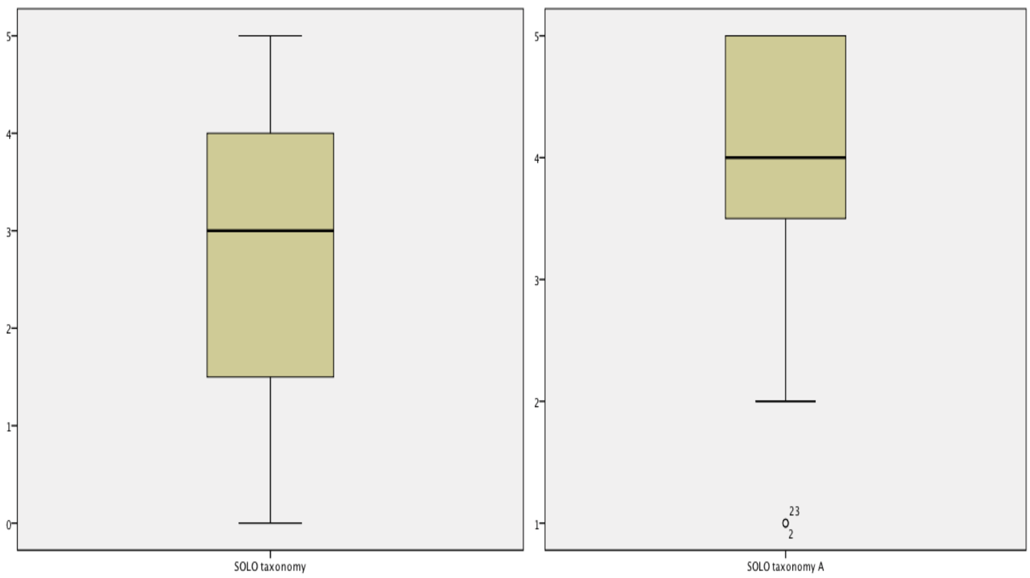

Figure 4.2.1 Inter Quartile Range

4.2.4. Analysis of Question 2.2

Q2.2 was ‘Suppose that you are increasing the temperature until 100°C and you can see the particles. Please draw what you imagine you would see as the temperature changes’ (Appendix 5). This was different from the multiple questions on page 1 of the questionnaire and the open-ended extended responses on page 2. Rather, Q2.2 asked students to use their imaginations to describe the particles as the temperature changes. Students’ answers to this question were categorised according to simplified elements of ‘The Particle Theory of Matter: The Kinetic Molecular Theory’. The Kinetic Molecular Theory (KMT) emphasises the movement of particles. It is based on the following five postulates:

1. All matter consists of extremely small particles.
2. All particles of one substance are identical.
3. The spaces between particles are very large compared with the size of particles themselves (in gases).
4. The particles in matter attract one another.
5. All particles of matter are constantly in motion (NSW Department of Education and Communities 1999-2011).

Each student’s drawing was categorised according to whether or not it included representations of the KMT postulates, and then the number of postulates in the pre-test and post-test were calculated for comparison purposes. The Wilcoxon signed-rank test (Table 4.2.4) was used to compare the sum of the postulates in the drawings of pre- and post-test answers to Q2.2. The p-value was .001 (<.05) and the null hypothesis is rejected. The results indicate a statistically significant difference between students’ pre- and post-test results based on the number of included KMT.

Table 4.2.5 Question 2.2 Wilcoxon Signed-Rank Test

	KMT1_A - KMT1	KMT2_A - KMT2	KMT3_A - KMT3	KMT4_A - KMT4	KMT5_A - KMT5
Z	-1.342[b]	-2.111[b]	-2.111[b]	-2.000[b]	-3.000[b]
Asymp. Sig. (2-tailed)	.180	.035	.035	.046	.003
a. Wilcoxon Signed-Rank Test					
b. Based on negative ranks.					

In addition to the sum of all postulates, each postulate was also compared for pre- and post-test in terms of percentages. In the accompanying pie charts, the green shading represents the percentage of students whose drawings included the relevant postulate of the KMT.

Figure 4.2.2 shows the percentage of students' drawings that included the first postulate, 'All matter consists of extremely small particles', was 84.2% in the pre-test and 94.7% in the post-test. This increase was not statistically different in the Wilcoxon signed-rank test, with the p-value of .130 (> 0.05) (Table 4.2.5).

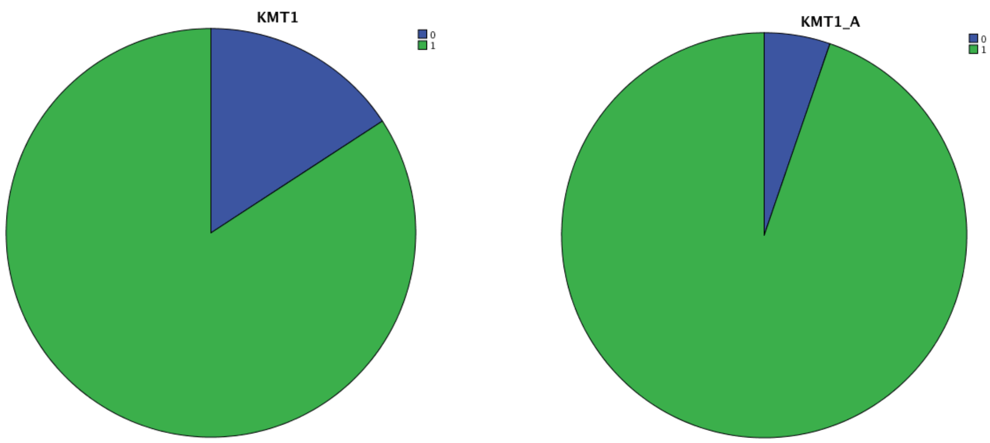

Figure 4.2.2 The percentage of students' drawings for first KMT postulate

Figure 4.2.3 shows the percentage of students' drawings that included the second postulate, 'All particles of one substance are identical', was 36.8% in the pre-test and

73.7% in the post-test. The large increase was statistically different in the Wilcoxon signed-rank test, with the p-value of .035 (<.05) (Table 4.2.5).

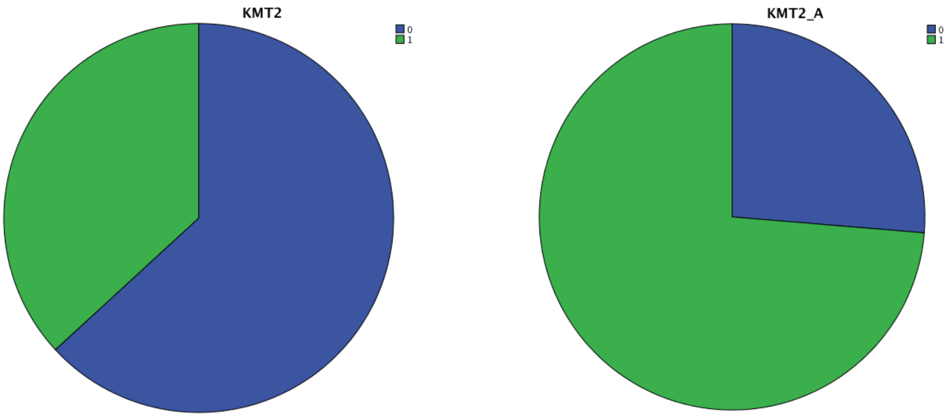

Figure 4.2.3 The percentage of students' drawings for second KMT postulate

Figure 4.2.4 shows the percentage of students' drawings that included the third postulate, 'The spaces between particles are very large compared the size of particles themselves', was 21.1% in the pre-test and 57.9% in the post-test. This large increase was statistically different in the Wilcoxon signed-rank test, with the p-value of .035 (<.05) (Table 4.2.5).

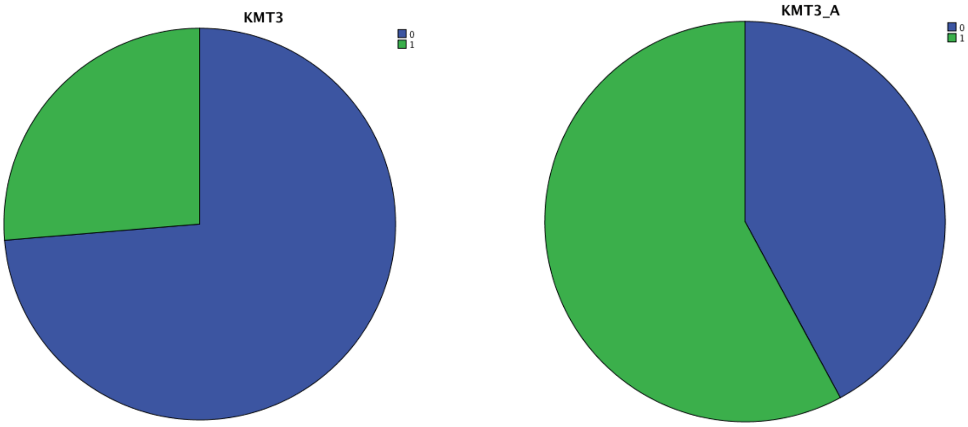

Figure 4.2.4 The percentage of students' drawings for third KMT postulate

Figure 4.2.5 shows the percentage of students' drawings that included the fourth postulate, 'The particles in matter attract one another', was 0.0% in the pre-test and 26.3% in the post-test. This means no student showed the postulate in the pre-test. The increase was statistically different in the Wilcoxon signed-rank test, with the p-value of .046 (<.05) (Table 4.2.5).

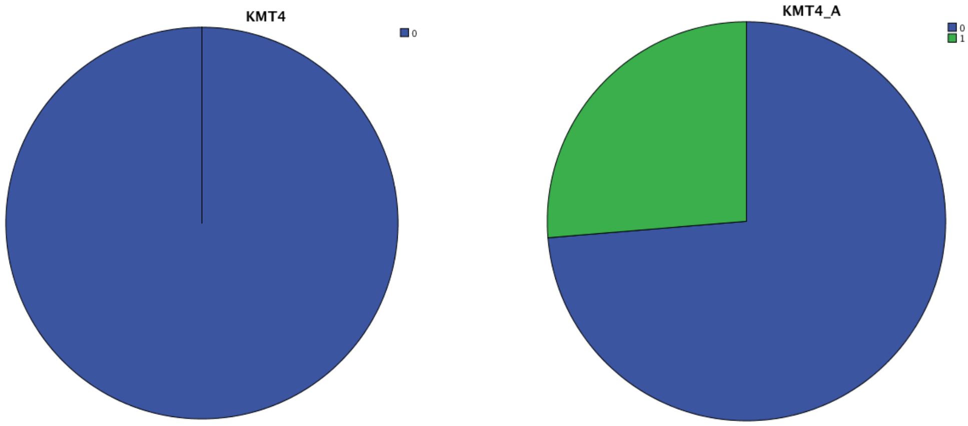

Figure 4.2.5 The percentage of students' drawings for fourth KMT postulate

Figure 4.2.6 shows the percentage of students' drawings that included the fifth postulate, 'All particles of matter are constantly in motion', was 15.8% in the pre-test and 68.4% in the post-test. This increase was statistically different in the Wilcoxon signed-rank test, with the p-value of .003 (<.05) (Table 4.2.5).

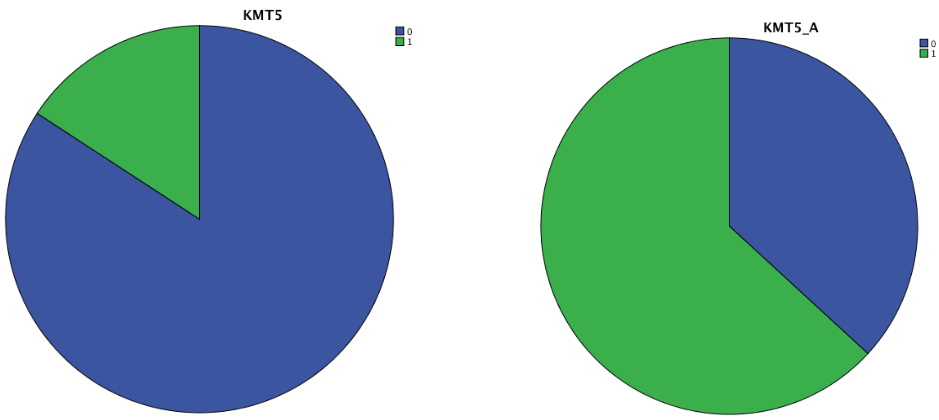

Figure 4.2.6 The percentage of students' drawings for fifth KMT postulate

Table 4.2.6 Question 2.2 Wilcoxon Signed-Rank Test Based on five postulate Test Statistics[a]

	KMT1_A - KMT1	KMT2_A - KMT2	KMT3_A - KMT3	KMT4_A - KMT4	KMT5_A - KMT5
Z	-1.342[b]	-2.111[b]	-2.111[b]	-2.000[b]	-3.000[b]
Asymp. Sig. (2-tailed)	.180	.035	.035	.046	.003
a. Wilcoxon Signed-Rank Test					
b. Based on negative ranks.					

4.2.4.1 Examples from students' drawings

This section reports on the drawings of four selected students, S4, S6, S7 and S13, in their pre- and post-test results with respect to the five postulates of the KMT. These students were purposefully selected to enable analysis of drawing among students who had the biggest differences in their pre- and post-test scores. In the first example, S4 included only the first postulate in his pre-test drawing, which shows matter (water) as small particles (Figure 4.2.7). These particles appear smaller in the second phase, which indicates his drawing did not include the second postulate. Nor did he show any kind of motion (fifth postulate), molecular attraction (fourth postulate) or comparison of the spaces between particles and the size of particles themselves (third postulate). In his post-test drawing (Figure 4.2.8), all particles of the substance were identical (second postulate). In addition, he showed some small lines near the particles to include the motion of particles (fifth postulate). While S4's drawing included only the first postulate in the pre-test, it included the first, second and fifth postulates in the post-test drawing.

Example 1: S4's pre- and post-test drawing

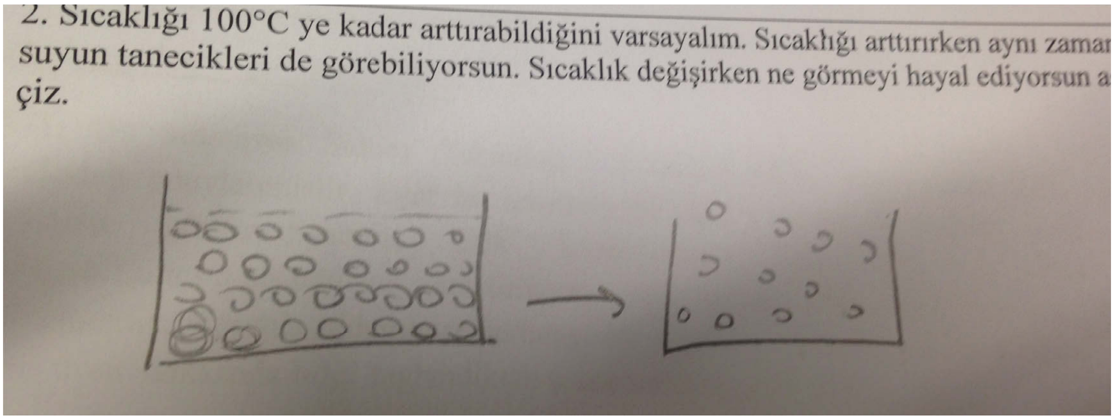

Figure 4.2.7: S4's pre-test Q2.2

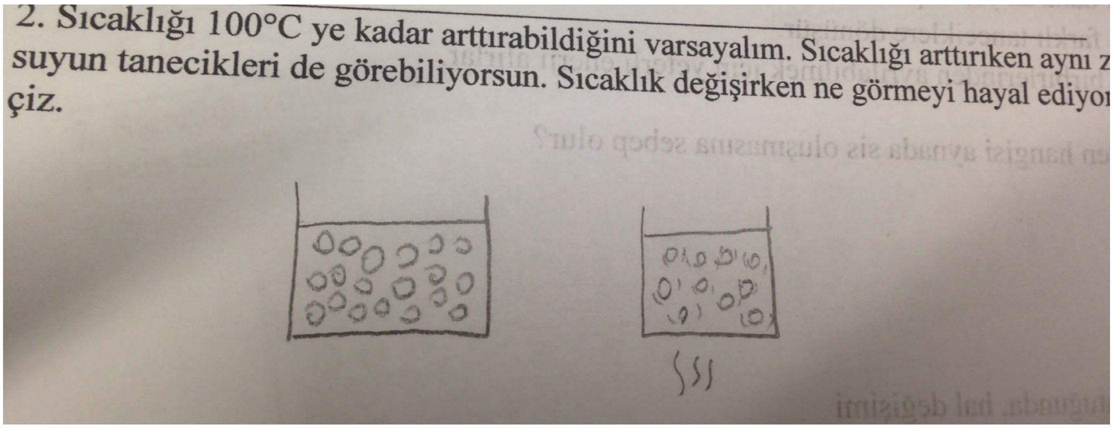

Figure 4.2.8: S4's post-test Q2.2

In the second example, we can see a difference in S6's pre- and post-test drawings. Figure 4.2.9 shows S6's pre-test drawing. She only drew the macroscopic view of water as the temperature changes and she did not show any particle in her pre-test drawing. Her drawing was therefore coded as 'zero', which means it did not include any postulate of the KMT. Her post-test drawing (Figure 4.2.10) was quite different. Here she showed the first postulate, the second postulate and the third postulate. She also wrote, 'Its kinetic energy increases as temperature increases' (see *isitildikca kinetic enerjisi artar* in Figure 4.2.10) in the liquid phase. This alludes to the fifth postulate. In summary, while none of the postulates was included in her pre-test drawing, she included the first, second, third and fifth postulates in her post-test drawing.

Example 2: S6’s pre- and post-test drawings

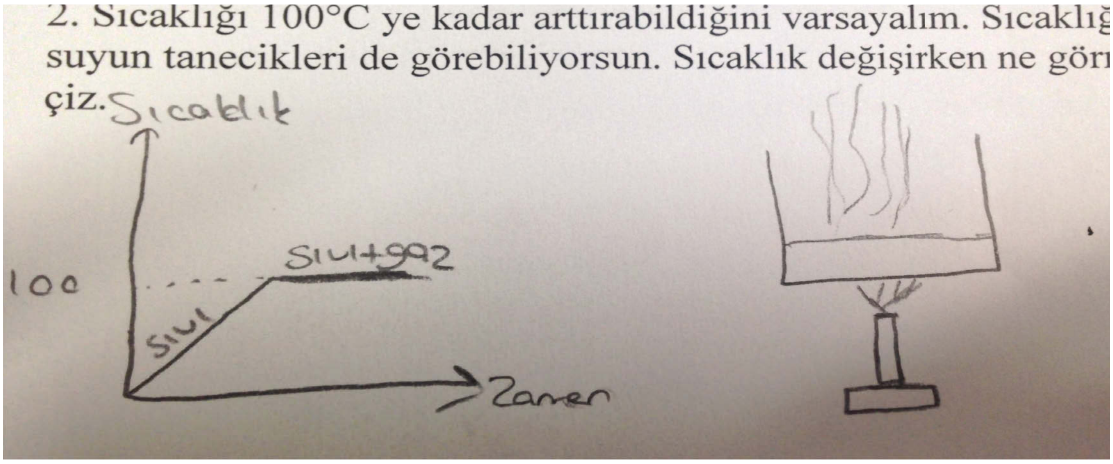

Figure 4.2.9: S6's pre-test Q2.2

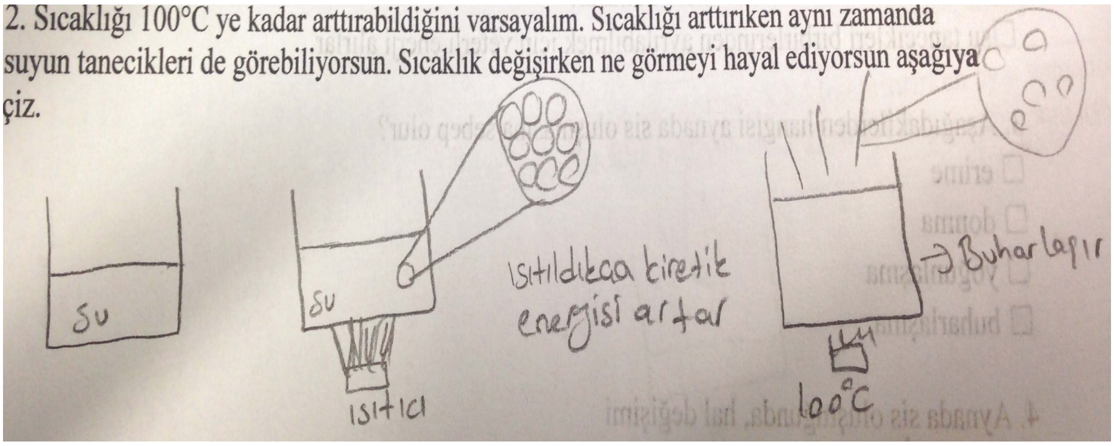

Figure 4.2.10: S6's post-test Q2.2

In the third example, S7 did not show any postulate in her pre-test drawing (Figure 4.2.11). She showed only the steam above the water (see *Buharlasma* in Figure 4.2.11). However, in her post-test drawing (Figure 4.2.12), we can see representations of the first, second, third and fifth postulates. She drew the identical particles with larger space compared to the size of particles. In addition, in the second and third beaker the particles are shown to move. While she did not show any of the postulates of the KMT in the beginning, she later showed all the postulates except the fourth.

Example 3: S7's pre- and post-test drawings

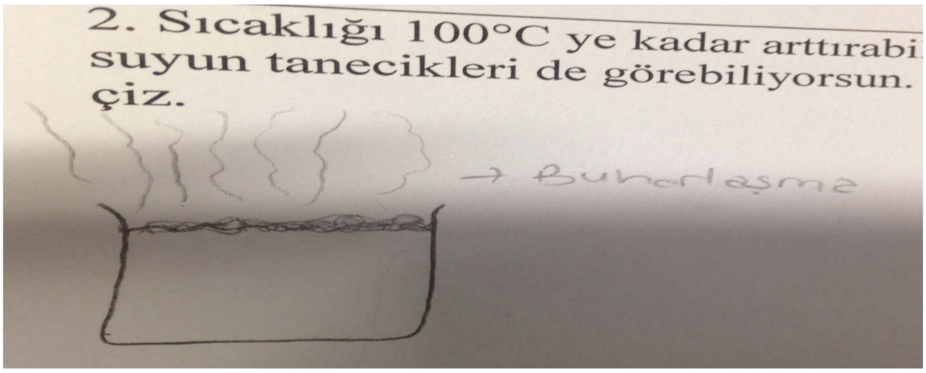

Figure 4.2.11: S7's pre-test Q2.2

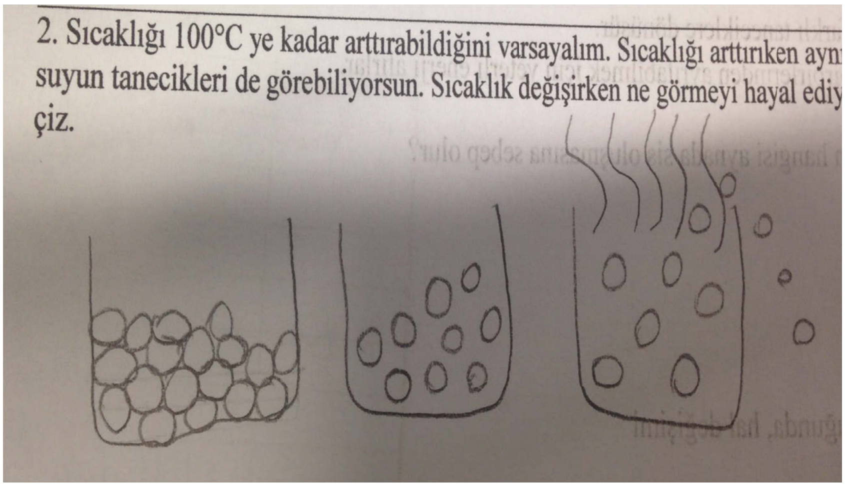

Figure 4.2.12: S7's post-test Q2.2

In the fourth example, S13's pre- and post-test drawings were totally different from each other. In the pre-test (Figure 4.2.13), particle sizes were different from each other for the same substance. She also wrote, 'I imagine different size particles for water' (see *su taneciklerinin boyutlarinin farkli olmasini hayal ettim* in Figure 4.2.13) near her drawing, as shown with an arrow. This demonstrates the inclusion of only the first postulate in her pre-test drawing. In her post-test drawing (Figure 4.2.14), even though she drew the particles differently from her pre-test, she tried to draw them as identical to each other (second postulate) and show the spaces between particles were very large compared to the size of particles (third postulate). In addition, she wrote near this drawing 'the particles are moving fast and fast' (see *tanecikler hizli hizli hareket ediyor* in Figure 4.2.14), (fifth postulate). Her post-test drawing therefore included the first, second, third and fifth postulates.

Example 4: S13's pre- and post-test drawings

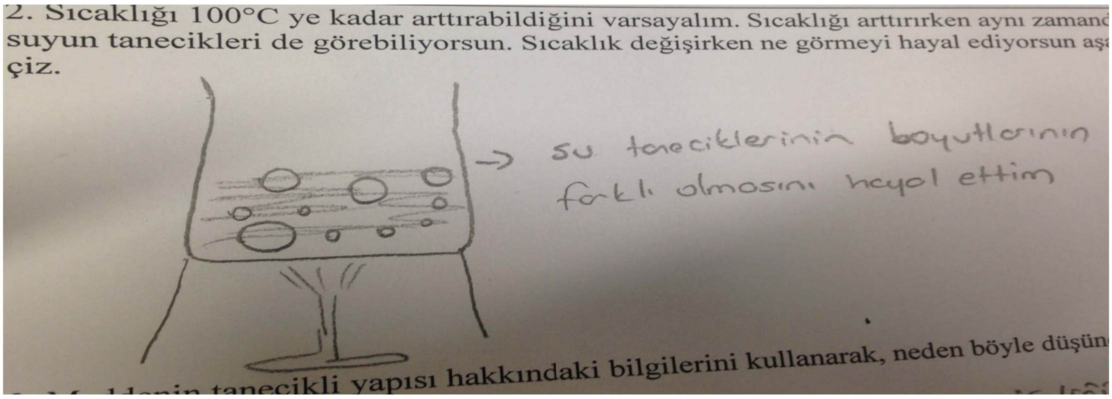

Figure 4.2.13: S13's pre-test Q2.2

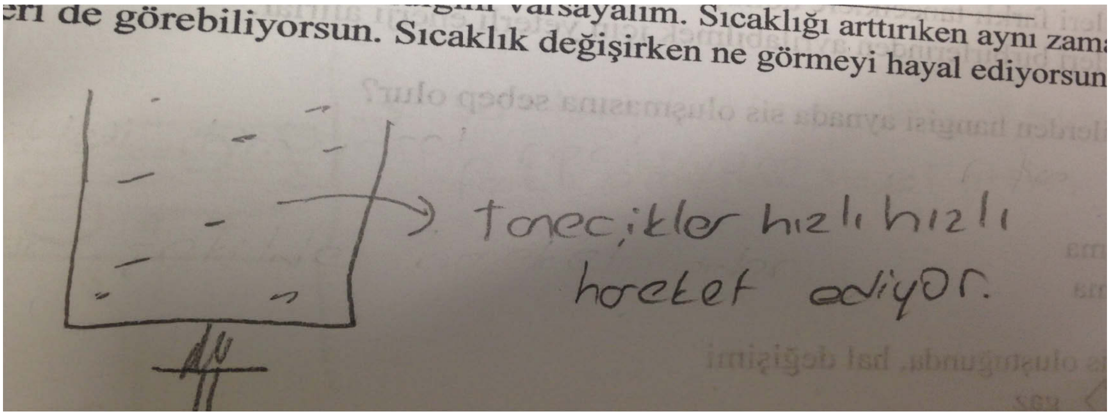

Figure 4.2.14: S13's post-test Q2.2

4.3. Creating animations (Phase 2)

4.3.1. Partner's interactions

To solve a given problem, students worked together in groups in pairs while creating their animations. There were 11 groups; 10 groups consisted of pairs and one group had three members. The term group is used to describe these pairs and the triplet throughout.

One member of each group held the mouse and drew on the computer while the partner observed and interacted with the drawing partner so as to understand what was being drawn. Students changed their roles periodically, holding the mouse or observing and commenting, while they were creating the animations. Their interactions were divided into the following five categories:

1. Seeking understanding of the partner's claim
2. Giving instructions to the partner
3. Adding new information
4. Advising and convincing
5. Technical discussion

Shown below are examples of each category using student dialogues to illustrate the interaction between the pairs of students.

1. *Seeking understanding of the partner's claim*

In S4 and S7's group, it was crucial for S4 to understand his partner's drawings. He was thinking that it should be a joint product. He did not want just to finish it up. He tried to understand his partner's drawings, so he always asked questions about them. As they discussed the solid particles, S4 interrupted S7's drawing even as S7 was trying to explain her ideas. Their dialogue is shown in Example 5.

Example 5: Dialogue between S4 and S7

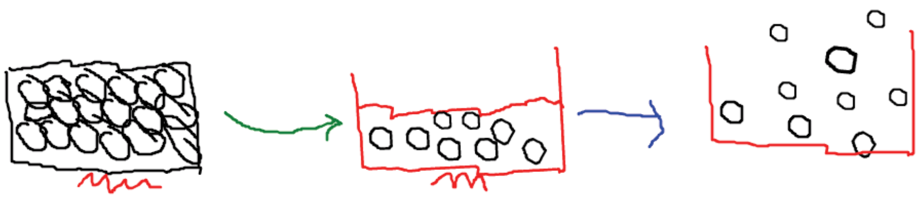

Figure 4.3.1: S4 & S7 animation

S4: But I still don't understand what are you doing now because they are all same particles.

S7: I think that they will be side by side.

S4: But how come and why?

S7: This one is the enlarged of this.

S4: And what is that?

S7: Is this one? *(pointing to solid)*

S4: Yes

S7: This is solid matter. When we look throughout microscope, this is solid, and that one will be liquid and after that we will put arrow from here and it will be gas. Did you understand? Now it is solid.

Even though students had ideas about what they were drawing, they needed to ask their partner about unclear concepts. Sometimes they needed advice or confirmation, but they also needed to learn the concept about which they were unsure.

In Example 6, S9 was not sure how to draw the gas state and he couldn't get an explanatory answer about it from his partner, S6. S6 mentioned the spreading of gas particles and S9 enlarged the molecules to spread to whole page. S6 realised that when they drew gas particles spreading they used the zooming button. When they used the zooming button, the particles not only spread out but also enlarged, which could cause a misunderstanding for the their classmates. This shows that S6 could not explain the behaviours of gas particles to S9, who just spread out the molecules without keeping them at the size S6 had described (Figure 4.3.2).

Example 6:

Figure 4.3.2: S6 & S9's solid, liquid and gas animation

S9: Leave like this. It is ok. We should save it in this form. How should we draw the gas phase?
S6:I don't know.
S9: Should we make something like evaporation?
S6: If you covered the whole back of the page, it would be good.
S9: Let's do like this.
S6: This one is bigger but I hope they *(classmates)* don't have misunderstanding because we make it larger and larger. We need to fix it because it can cause misunderstanding *(they watch together). (S9 tries to make some last touches)*

S6: I think it is good.

S9: *(calls teacher)* Could you check it please?

In addition, students talked about partner interactions in the interviews. They indicated that they were pleased to have been working in groups. Interview example 1 is an example of category 1: *Seeking understanding of the partner's claim.* The researcher asked all groups about the effectiveness of group work. S1 and S8 said they found it useful because they got a chance to exchange their understanding with their partner. An extract from the interview with S8 is shown below.

Interview example 1:

R: While you were creating your animation, you drew with your partner. Did you learn something during discussion? I mean was group work useful for you?

S8: Of course useful

S1: Yes

S8: Because we exchange our ideas, our thinking.

R: Could give an example of exchanging your ideas during discussion?

S8: For example, I asked to S1 about molecules? She explained that oxygen will be in the centre and others will be hydrogen. Then S1 asked me whether the drawing of solid molecules is round or rectangular.

The teacher also commented that the partner interactions were an effective feature in the learning process. She claimed that while students create their animations in groups, they 'thought aloud' and their partners listened to their thinking. Therefore, they corrected their mistakes; they added new information to their partners' ideas during the group discussions. The teacher also added that if students created the animations individually, their ideas would stay the same as they were. Therefore, group work were created more effective learning environment than individual work for students.

2. *Giving instructions to the partner*

Partner interactions had different shapes in each dialogue. In some groups, giving instructions or orders to the partner took place rather than offering conceptual explanations. Example 6 demonstrates this. S17 was drawing the animation while S16 gave directions to S17 without any explanation to her partner (Figure 4.3.3). She was just trying to complete the animation according to her thinking or understanding and did not ask for S17's ideas while drawing the animation.

Example 7:

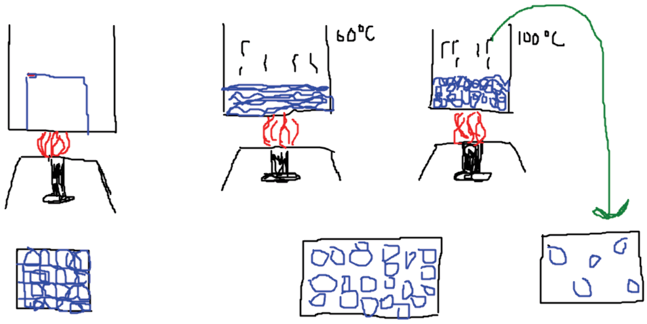

Figure 4.3.3: S16 & S17 animation

> S16: You will draw liquid in the second one and you will draw gas in the third one. Draw one two *(round shape)* more here too, it will be enough, draw here too *(continues giving orders)*. Now draw the gas.
>
> S17: I'll draw something in evaporation.
>
> S16: Draw in here.
>
> S17: Should I draw arrow?
>
> S16: Draw here here *(angry voice)* what are you doing?
>
> S17: Just highlighting, should I make steam?
>
> S16: You know better. I think draw three to five *(round shapes)* over there it will be enough.
>
> S17: I will do it like this (draws round shape).

In addition, students in groups often agreed with each other and respected the opinions of their partners. They also understood that each partner could freely contribute to the group. In example 8, S8 had some ideas about how to draw and tried to get agreement from S1, who accepted S8's ideas. After S8's contribution to the animation, S1 also presented her ideas to S8 about a change in size of the solid particles and S8 agreed with them (Figure 4.3.4).

Example 8:

Figure 4.3.4: S1 & S8's solid and liquid animation

> S8: Yes we will make gas phase later. Is it ok like this?
>
> S1: Yeah OK.
>
> S8: Let's do like this and joint from here.
>
> S1: Yes, let's combine them.
>
> S8: Should be like this.
>
> S1: Could we enlarge it? Firstly, we should make the solid larger.
>
> S8: Yes, OK.

In interview example 2, S9 explained how his partner gave instructions to him and also explained her (S6) recommendations about their animation. He also claimed that their partner interactions influenced their work. The researcher asked whether it would be different or not without your partner. He replied, 'Definitely'.

Interview example 2:

R: Do you remember anything else from your discussions?

S9: I don't remember now but we created the animation together. We both thought about it. For example, before I was thinking that there should be one beaker and the ice block should melt in the same beaker. However, S6 recommended that it would be better if we showed melting in two different beakers. She was right. It looks better now.

R: You mean, if you drew this animation alone, it would be different?

S9: Definitely.

3. *Adding new information*

Some partner interactions helped students to become aware of deficiencies in their conceptions of the states of matter, particularly about the motion of particles. In Example 9, S4 asked his partner, S7, about motion but S7 had not thought about the 'motion of particles' until she heard it from S4. She may not have been aware of it. When she heard the word 'motion' she was silent for seconds and tried to delete the animation and start again, but S4 did not want to do this. After failing to show motion on the initial animation, they deleted it and created a new animation (Figure 4.3.1).

Example 9:

> S4: Don't we add motion? (*Long pause*)
>
> S7: Oooh are we going to make motion?

S4: Isn't it our aim?

S7: Then do we need to delete it all?

S4: Stop

S7: But we need to add motion.

S4: Hmm, how should we do it?

In Example 10, S12 realised S24's misconception about the size of particles and wanted to emphasise it by asking, 'Why?'. S24 thought the particles became larger while turning from solid to the liquid phase. S24 explained their arrangement rather than their change in size. S12 then thought deeply about larger particles but drew particles of the same size in a regular arrangement rather than larger particles (Figure 4.3.5).

Example 10:

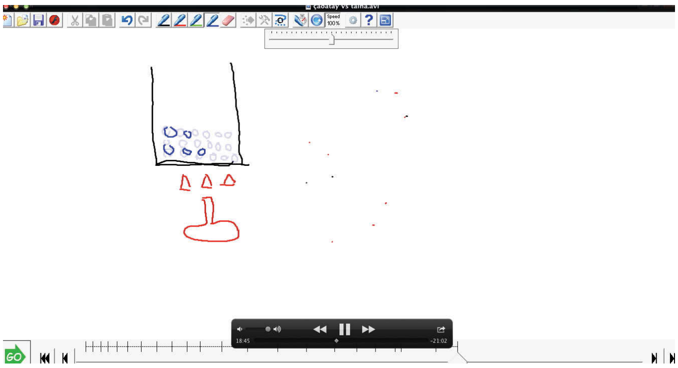

Figure 4.3.5: S24's liquid part animation

S12: Let's draw liquid phase of it.

S24: Yes we should draw larger particles for liquid phase.

S12: But why? We should draw more regular because particles are more regular *(than S24's drawing)* in the liquid phase.

S24: silent *(tries to draw more 'regular' particles of same size)*

Interview example 3 shows that S4 contributed new ideas to S7 conceptualisation of states of matter. S7 was not aware that liquids do not have spaces between particles but they just flow about each other. S4 also added that she learned the movement of particles from her partner S7. They both agreed that without partner interaction animation would be totally different.

Interview example 3:

S7: For example, I was thinking that from solid to a liquid state, the spaces between particles are increasing but they only pass above each other and flow easily.

R: What about you S4? While you were discussing this with your partner, is there anything that occurred in your mind that was different from your previous thinking? I was thinking like this but 'ahaa' it is like that?

S4: Actually, the idea of the movement of molecules is from

S7. I mean movement not only in one particle, the whole kinaesthetic movement idea. I learned the idea of the whole movement.

R: OK. If you didn't work with your partner, would it be different that time?

S4: Yes, it would be different

S7: I also think that it would be different.

4. *Advising and convincing*

Some group partners offered advice to each other while working towards a common aim. They tried to advise the partner about exactly what they had planned.

In Example 11, S24 gave advice to S12 about the movement of particles using sentences containing 'should' and continuing with 'because'. His suggestions were about both the microscopic and macroscopic interpretive levels of the phenomenon. He mentioned that the spinning of gas particles was at the microscopic level and steam above the liquid was macroscopic (Figure 4.3.6).

Example 11:

Figure 4.3.6: S12 & S24's from solid to liquid animation

S24: Let's watch it. Actually time frames are also in harmony.

S12: Yes.

S24: We should make here longer because it is going faster but at least they are spinning. We should turn it like this. Is it OK?

S12: OK.

S24: Let's watch from here, we can arrange it, we should arrange molecules better, we should spin them more and should add some steam on top of them and we can specify them as gas.

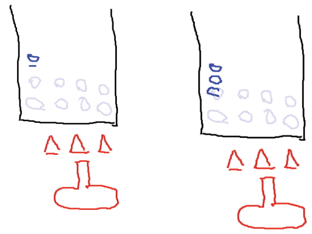

Figure 4.3.7: S12's gas particles animation

After S24 had advised S12 about how to draw gas particles spinning, he gave the mouse to S12 to do the drawing S12 started to draw the particles but S24 interrupted him and tried to convince him to adopt his views. S24 took back the mouse and showed S12 how to draw gas particles, deleting S12's molecules that were very close to each other. S24 drew molecules in the gas phase far from each other and in an irregular pattern. S24 returned the mouse to S12 but continued to explain where S12 should put the molecules.

S24: If you want, you can do it (Figure 4.3.7).

S24: I think we shouldn't make it like this.

Figure 4.3.8: S24's correction for gas particles animation

S24: Make, undo. I will show it to you how to create *(tries to convince S12)* draw one to here and one to here (Figure 4.3.8).

Figure 4.3.9: S12's motion to heat animation

S24: Draw in here too, and give motion to heat.

Even though S12 received directions and advice from S24, his drawings inferred that he had other ideas in mind. He thought that molecules could not move without the application of heat and indicated motion on each molecule (Figure 4.3.9, shadow of molecules shows their previous position) after they were heated up.

Interview example 4 shows S18's dialogue about partner interaction. He mentioned that he and his partner decided together and gave advice to each other to show the changes in heat during the different phases of matter. In Interview example 5, S20 mentioned that he and his partner tried to convince each other about the arrangement of particles.

Interview example 4

R: While you were creating your animation, you discussed with your partner. Was it useful?

S18: Yes was useful

R: Could you give an example?

S18: We didn't give heat before. But then we thought that it couldn't change phases without heat. We decided to write degrees to show up heat. We wrote the ones are solid, liquid, and gas states on the animation.

Interview example 5

M: I said let's draw as liquid but my partner said no we should show the spaces between molecules. I said No and I won.

5. *Technical discussion:*

Students created their animations using a software program (K-Sketch), which meant they discussed with their partners not only conceptual ideas but also technical issues such as drawing pens, saving buttons, the speed of animations and the colours of molecules. In Example 12, first they talked about the colour of steam and decided on a blue colour. They then discussed the direction of steam. Finally, they talked about the time frames of the animation for each state (Figure 4.3.10).

Example 12:

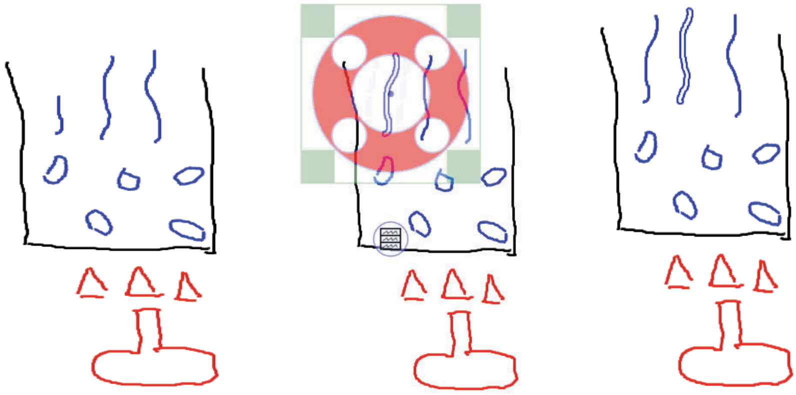

Figure 4.3.10: S12's steam animation

S24: Let's show the steam? Should it be blue colour?

S12: Yes blue again.

S12: Movement to above?

S24: Is it like this? Now we should delete it *(heat)* from bottom and show that it is gas. We should arrange time differences. Actually our timing is long.

S12: yes

S24: It is not a problem we can arrange it now. We have to make same time differences between them. OK. Let's leave like this.

S12: Yes.

In Example 13, S12 and S24 tried to decide the appearance of the animation. S12 was thinking that they should add the word 'liquid' at the bottom part of liquids. S24 agreed but then S12 decided to leave the animation as it was. S24 supported him not changing the animation and they agreed in the end (Figure 4.3.11).

Example 13:

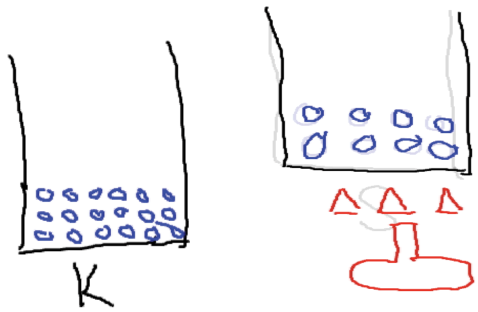

Figure 4.3.11: S12 & s24's solid and liquid particles (K=Kati)

S12: I wish we showed it like 'S' in liquid *particles (S for Sivi means liquid in Turkish)* like we did for solid particles as 'K' *(K for Kati means solid in Turkish)*.

S24: Should we make like that?

S12: Or may be it is understandable.

S24: I think it is understandable because of movements. I think we should save like this.

S12: OK, agreed.

In Example 14, S24 tried to draw what was in his envisioned and advised his friend. He suggested drawing both heat and motion to the particles. After this advice S12 was also eager to 'give' motion to particles (Figure 4.3.12).

Example 14:

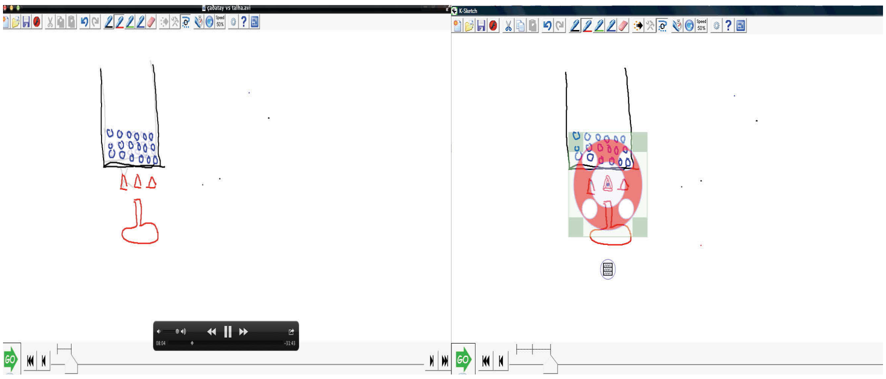

Figure 4.3.12: S24's giving motion to heat animation

S24: We draw above like that? Should we give heat, too?

S12: Yes, let's heat it from bottom.

S24: First, we should draw our molecules in the same way, then should draw the heat from bottom part. And we didn't give any motion we should make them movable. (*Researcher comes near and asks them what they are doing and they continue).* Let's go to the beginning of the animation and arrange the time differences between states for heat. What do you think? Is it OK? Should we arrange its speed?

S12: We should decrease its *(speed)* more.

S24: Should we decrease more? Is it OK?

S12: Now it is time to give them motion.

Interview example 6 includes students' dialogue about technical issues. Here, S21 first mentioned the shapes of molecules then the researcher asked S21 about conceptual discussions with her partner. However, she also continued with commentary about technical issues like amount of heat.

Interview example 6

R: What did you mostly discuss with your partner?

S21: We discussed about shapes.

R: About concept?

S21: About concept; how much heat, what will happen after heat etc.

In addition to the five categories shown above, an important consideration is the implicit and explicit conversations of the students. They often did not make explicit statements connecting the animations and attributes of the phenomena they were addressing, for example, the size or colour of particles. There are a small number of these cases.

In Example 15, the students do not explain why they do not think the particles are bigger in different states. This is an implicit 'conversation'. To make it explicit, they need to explain that all the particles of one substance are identical and how this will phenomenon appear in the animation. On other occasion they simply referred to the image without elaborating on the details verbally

Example 15:

S6: This one is bigger but I hope they *(classmates)* don't have misunderstanding because we made them larger and larger. We need to fix it because it can cause misunderstanding.

Example 16 shows a commonly occurring exchange between partners. S1 and S8 were in agreement but they did not explain the connection between the phenomenon and their thinking. They wanted to enlarge the solid particles but they did not give a reason.

Example 16:

S8: Yes we will make gas phase later. Is it ok like this?
S1: Yeah OK.
S8: Let's do like this and joint from here.
S1: Yes, Let's combine them.
S8: Should be like this.
S1: Could we enlarge it? Firstly, we should make the solid larger.
S8: Yes, OK.

By contrast, in example 17, we can see an explicit dialogue, with the students using 'should' and 'because' to match their drawing with the phenomenon of particle size with their drawing.

Example 17:

S12: Let's draw liquid phase of it.
S24: Yes we should draw larger particles for liquid phase.
S12: But why? We should draw more regular and also identical because particles are more regular *(than S24's drawing)* in the liquid phase.

The next section explains and gives examples of the teacher's guidance of students' representation creation processes. The teacher generally led the conversations about phenomena to clarify the students' understanding.

4.3.2. Teacher's guidance

The teacher actively guided the students and provided scaffolding to improve and organise their understandings by questioning, shaping and assessing their representations. The analysis of the teacher's scaffolding identified nine elements, which are categorised as follows:

1. Repeating a student's previous sentence and asking further questions
2. Reminding students of what they are attempting
3. Clarifying the student's claim
4. Summarising their drawings and eliciting information

5. Encouraging them
6. Providing additional direct information
7. Highlighting significant omissions and recommending changes to address them
8. Asking a reason for something or seeking an explanation
9. Providing misleading comments.

Each category of the teacher's guidance is explained with evidence from student–teacher dialogues.

1. Repeating students' previous sentence and asking explanations

The teacher sought to support students during the animation creation process. While the students were creating their animations, she gave them different kinds of guidance. First, she focused on the students' explanations. While students were talking about their animations, she interrupted them by repeating their last sentence to confirm their understanding. In Example 18 (Figure 4.3.13), the teacher asked questions to help S4 and S7 think about the spaces between particles and the distribution of particles in the gas state. She then confirmed the correct answer by repeating S7's explanation.

Example 18:

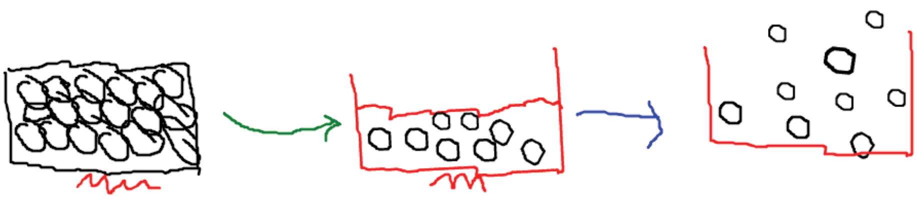

Figure 4.3.13: S4 & S7's animation

S7: The most irregular pattern will be in the gas phase.

T: Highly irregular pattern? And what happens?

S4: The capacity of movement increases.

S7: In other words, its kinetic energy increases.

T: Namely, its energy increases.

In Example 19 (Figure 4.3.14), the teacher focused on S9's assertion about the particles' behaviour when turning to gas. S9 was indicating that when the substance turned into the gas phase, the spaces between particles enlarged, which is right. However, S9 misconceived the structure of particles and their change in size, but the teacher did not correct him. S6 and S9 continued to draw their animation while the teacher proceeded to guide another group. It seemed that the teacher was seeking primarily to ensure that the animation represented or explained their view rather than, at the time of creating the animation, that the animation correctly represented a standard scientific conceptualisation.

Example 19:

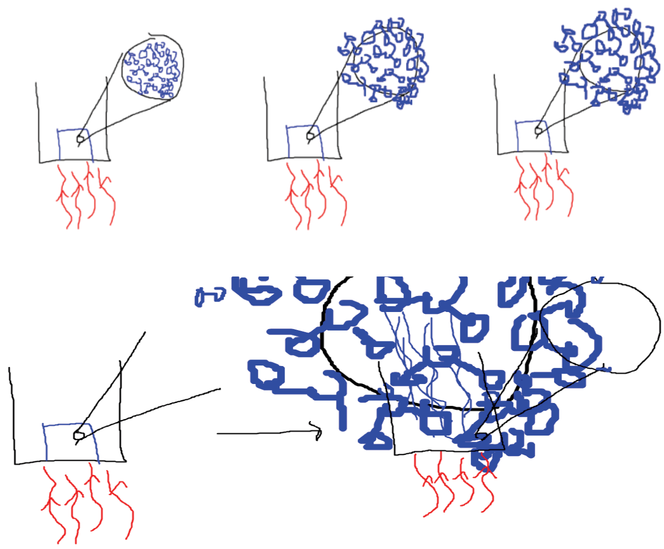

Figure 4.3.14: S6 & S9's animation

S9: We will turn to gas phases.

T: You will turn to gas and what will happen when they are gas?

S9: They will become larger and when they are larger the spaces between them will be larger, too. We have to make them more separate.

2. *Reminding students of what they are attempting*

The teacher observed the students while they created their animations and discussed them with their partners. She reminded them that they were not only creating animations at the macroscopic level but also at the microscopic level. Therefore, they should not forget to look through an immensely powerful imaginary microscope while creating the solid, liquid and gas animations. She wanted to make sure all the students understood that they were creating micro-level drawings of particles. She came to each group and reminded them of this. In Example 20, the teacher asked them for the microscopic view and S1 explained the combination of particles. After the teacher prompted them for the microscopic view of particles, they added bonds to their particles in Figure 4.3.15.

Example 20:

Figure 4.3.15: First part of S1 & S8's animation

T: What do you imagine from a microscopic view?

S8: We will draw the solid particles close to each other. We are trying like that.

In example 21, S12 and S24 were not sure what they needed to draw. At first they just drew two ice blocks and asked their teacher what they should draw. The teacher reminded them to think about the microscopic view of the particles without describing what this might be like. After this reminder, they deleted their first drawings and started to draw particles in the solid state (Figure 4.3.16).

Example 21:

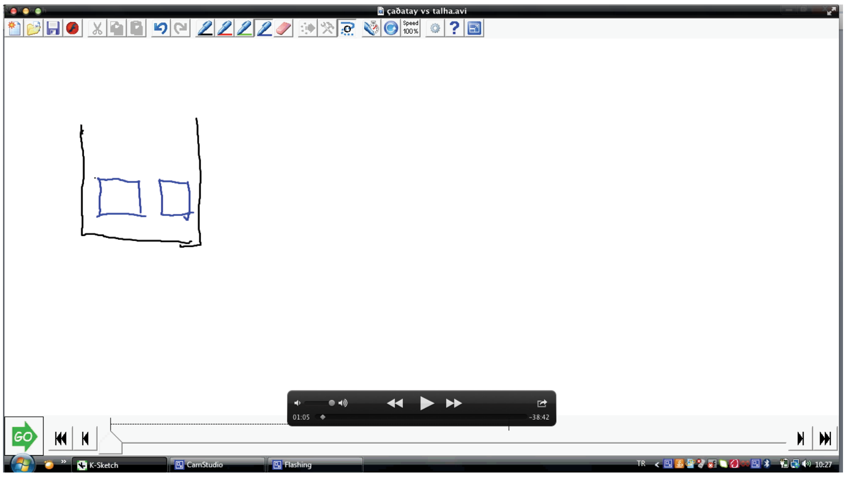

Figure 4.3.16: S12 & S24's first drawings for solid

S24: Do we need to show their particles, molecular structure?

T: Yes, you are thinking that you are looking through the microscope to solid, liquid and gas.

S24: For example we have drawn like this, should we make round, round things in their backside, what should we do?

T: How you want to draw, you should draw as you wish. You will show solid and also molecules of solid. In other words, you will show their microscopic views, what the solid molecules are doing inside of solid or liquid and gas state.

3. *Clarifying the claim*

The teacher tried to interact with the groups by asking that what they were doing or what they were creating. She encouraged the groups make claim of their ideas. In Example 22, she asked the group what they were doing at that moment (Figure 4.3.17). S1's answer was scientifically correct. They were drawing the distribution of solid particles and explained that they had strong interactions.

Example 22:

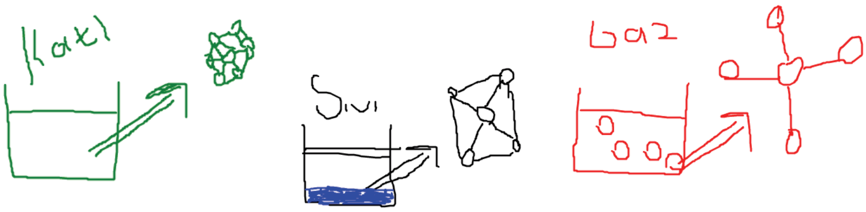

Figure 4.3.17: Second part of S1 & S8's animation

T: What are you trying to show?

S1: There are strong interactions between solid particles; therefore, I'm drawing the bonds.

S8: Let's draw one here and write as solid.

In Example 23, the teacher pointed to the solid particles of S4 and S7's drawings, expecting an explanation. The teacher listened to their scientific claims about change of state and agreed without further comment.

Example 23:

T: (Figure 4.3.13) What were these first drawings?

S4 & S7: Solid.

S7: They had more regular patterns and particles were more close to each other, they are further now.

S4: Particles’ energy will increase. They will also be further from each other by increasing movement capabilities.
T: Yeah.

Interview example 7 is one of the right examples for this category *‘Clarifying the claim’* because S21 mentioned that their teacher asked them what they were doing or what they were creating. The dialogue between the researcher and S21 is shown below.

Interview example 7
R: Did your teacher help you while you were drawing?
S21: Our teacher was watching us but not say anything about our comments but still was OK.
R: May be she didn’t say anything or not any help?
S21: No our teacher came to near us. She asked us what we were doing? We explain our thinking and she didn’t say anything about our decision.

4. *Summarising their drawings and eliciting information*

The teacher summarised what she understood from the groups’ animations. Her aim was to compare the ideas the students understood from the animations and what they tried to draw. She did not seek to tell students the right answers while she was summarising their animations. Rather, she sought to understand their current thinking about the state of matter. In Example 24 (Figure 4.3.18), she asked about the structure of liquid particles. S13 agreed with the teacher’s comment and explained that they imagined liquid particles to be like lines. The teacher continued to press on the microscopic view of particles, but S13 was sure that these are the right structure of liquid particles. The teacher did not comment.

Example 24:

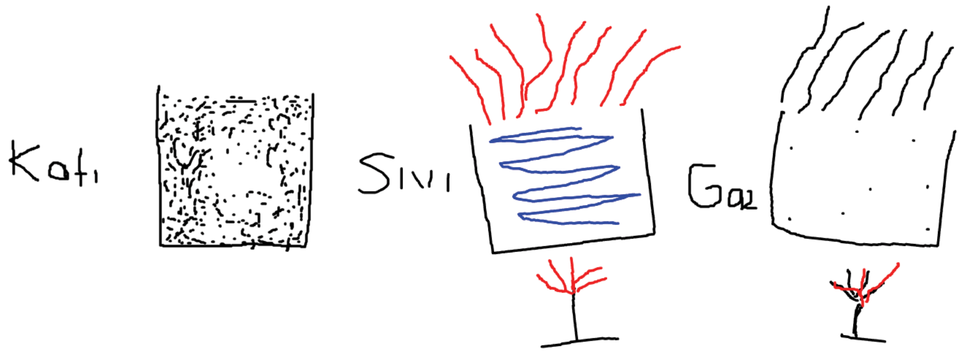

Figure 4.3.18: S13 & S14's animation

T: The liquid particles are like lines?

S13: Yes we imagined like this.

T: You are saying that when we look through the microscope we see the particles like that.

S13: Yes, the liquid particles are like these lines.

In Example 25 (Figure 4.3.19), the teacher asked S20 and S25 about the solid particles, but S20 was not sure about what they were drawing. After the teacher's question, he thought that he did something wrong and intended to change it. The teacher tried to understand their drawings by asking another question. She guided them by asking whether they had drawn solid matter (macroscopic) or particles (microscopic). S20 then thought about particles and explained that they would draw particles later.

Example 25:

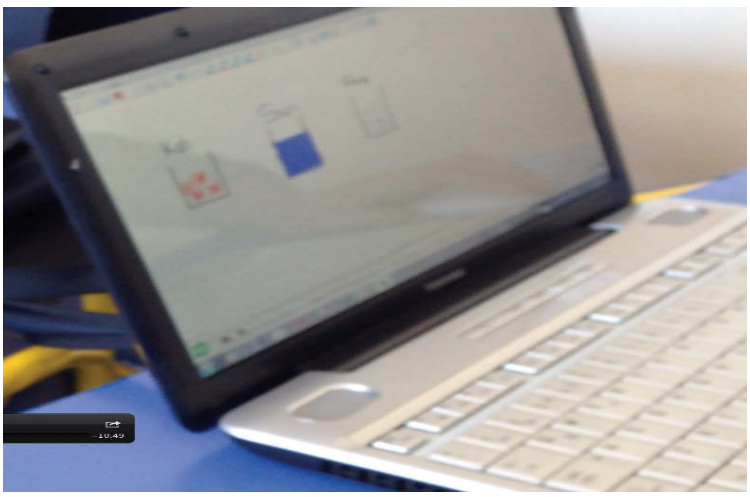

Figure 4.3.19: S20 & S25's animation view

> T: Are they three solids or anything else?
> S20: We can do anything else, too. It doesn't matter.
> T: No no, I mean that in the solid phase, are these molecules of solid or solid matter by itself?
> S20: They are solid matters; we didn't draw solid molecules yet.
> T: OK I was just asking.

In interview example 8, S6 said that the teacher helped them by looking at their animation and getting confirmation of what they had done. In other words, the teacher checked their animation, summarised their drawings and checked whether she had understood what they intended to say and show about states of matter.

Interview example 8

R: While you were creating your animation, did your teacher support you? She came to near you and talked about your animation. Was this useful or not?

S6: It should be helpful because she helped us while we were creating like how to do what to do.

R: Could you give an example?

S6: Generally, while we were creating, she explained more. For example, 'Did you do this one like this, didn't you?'

5. *Encouraging them*

The teacher gave positive feedback that focused on students' improving generally rather than on specific conceptual outcomes. In Example 26, even though the teacher encouraged S3 and S5, they did not want to talk about their animation. She then asked for their ideas about the animation. S5 did not want to explain it; he simply explained the change of phases. He did not respond to the teacher's encouragement. In the teacher interview, the teacher said it is very hard to get S5 to do his work. The teacher said, 'I am surprised that he spent that much time on the animation. He does not like studying in our education system but his imagination is very strong.' She also added that S5 could not draw what he imagined so he could not explain his animation to the class. He also realised that he couldn't explain his thinking on their animations so he wanted the stop his explanation. He realised his mistakes while he was explaining the animation.

The teacher had great confidence in S5. She said, ‘If he draws it again, he will have a great animation.’

Example 26:

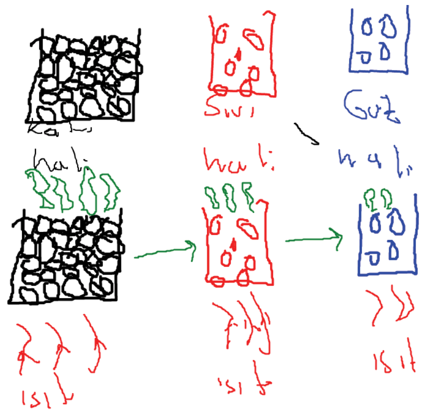

Figure 4.3.20: S3 & S5's animation

> T: Oooo! Looks like you have a pretty much improved your animation. Explain to me what happened, what has changed?
>
> S5 & S3: (Silent)
>
> T: Yes S5.
>
> S5: Yes my teacher *(He doesn't want to talk).*
>
> T: What did you do?
>
> S5: Nothing, we are just trying to do something.
>
> T: Yes what did you draw until now?
>
> S5: We are drawing liquid. It was solid before then turned to liquid and it going to be gas now.
>
> T: And from here?
>
> S5: We drew the first phases of matters.

In Example 27, the teacher went to S12 and S24's desk and showed her high expectation for their animation. This was the only group that the teacher encouraged in this way. The group was eager to draw the animation, and S24 even continued to draw it during the break from class time. In the interview with the teacher, she also recollected that this is one of the two groups who indicated the motion of solid particles.

Example 27:

(Teacher goes to near 24) T: Guys, I'm expecting extraordinary things from you.

6. *Providing additional direct information*

The students' engagement with their animations clarified for students how they were expected to develop important science ideas during the process. Therefore, the teacher was required not to give direct conceptual information to students during the animation process. However, in a few student–teacher interactions, the teacher did give direct conceptual information to the groups. In Example 28, S7 was aware that the gas particles should have motion but he needed confirmation from the teacher. She confirmed the movement of gas molecules and also added information about solid particles. She explained the vibration of solid particles and how to add motion to them, such as spinning.

Example 28:

S7: (Figure 4.3.13) Do we need to give motion to those? (Pointing to gas molecules)
T: Yes it would be better if you can give motion. For example, firstly I mention the vibration because of vibration of solid molecules.
S4: Hiii? (He listened and tried to understand.)
T: Actually if you give motion to them in their own places, and spinning while turning to liquid phase...

In Example 29 (Figure 4.3.21), S9 was thinking they had completed their animation. He called the teacher to their desk and sought confirmation on how to complete the animation. The teacher gave them direct information about 'adding motion' instead of instructing them in broad terms on how to improve their animation. The teacher also informed them about the vibration of solid particles. The interesting point was S6's comment. She mentioned that all matter was in continuous vibration but her group did not show any vibration or movement in its animations.

Example 29:

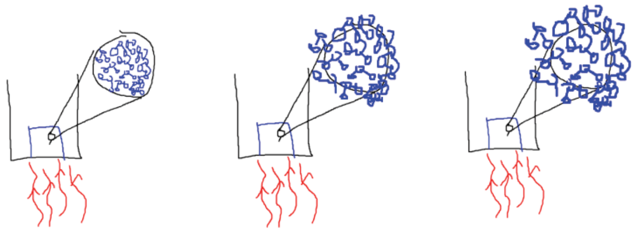

Figure 4.3.21: S6 & S9's solid, liquid, gas particles animation

S9: Is something missing?

T: What can we add? Your other classmates tried to add motion.

S9: Motion?

T: Vibration to solids.

S9: Really (very surprised).

S6: It is very ridiculous because matters are always in vibration.

T: In solid phase?

In interview example 9, it is evident that the teacher contributed critical scientific information to the group, that is, 'the vibration of solid molecules'. S7 claimed that they were thinking about motion but that vibration did not come to mind.

Interview example 9

S7: Yes she gave us some ideas. For example, she guided us about motion of particles. She said you can vibrate them, or you can give different movements to particles. If our teacher doesn't guide us, we would give direct motion to the molecules not vibration.

R: You mean that you didn't think about vibration, you just thought movement?

S7: Yes, we were thinking about motion but then our teacher came to near us and mentioned about vibration of molecules but we couldn't add vibration exactly.

However, in the interview the teacher said, 'I never say anything directly about the concept but I gave more additional information to those groups of students. I tried to ask open-ended questions. For example, one of the groups was thinking that solid particles have more spaces than liquid particles. I asked open-ended questions like, 'how the solid particles behave differently, think again, than liquid particles?' In the end this group also reached the correct arrangement of particle. This shows that the teacher intended not to give additional information to students, but some of her questions and statements shown above also provided direct information to students.

7. *Highlighting significant omissions and recommending changes to address them*

The teacher used scaffolding and teacher–student discussions to guide students during the animation creation process. However, a few times the teacher influenced the students to change the way they imagined states of matter to be. The teacher reported, ‘Some students got the idea very quickly; some students had difficulties understanding what to do. I gave more support to students who are not good in chemistry and do not have any idea about solid, liquid and gas particles.’ In Example 30 (Figure 4.3.13), she asked S4 and S7 why they did not give any motion to solid particles, even though they had mentioned the vibration of particles. She later expected to see vibration in this group’s animation but no representation of vibration was evident in the animation. She repeated the question. The group explained that they could not show it on their animation but they would describe the motion when explaining their animation to their classmates.

Example 30:

> T: Your visualisation in the animation would be good. I thought that you would draw like this because you mentioned vibration. If these ones had vibration, we would have good results. *(After a while teacher goes near students to check that whether they draw vibration or not?)*
> S4 & S7: Silent
> T: Did you give motion?
> S4: Open it she wants to see it
> S7: We didn’t give any motion.
> T: Couldn’t give it?
> S7: We will mention it while explaining our animation.

The following three interview examples indicate the teacher instigated some changes to students’ animations. However, S8 and S5 denied that even though the teacher recommended some changes they could not or did not make them.

Interview example 10

R: While you were drawing your animation, your teacher was walking around you. Did she help you?

S8: Yes. For example I asked to her how could we draw molecules. My teacher explained to us but we couldn’t draw.

Interview example 11

R: For example?

S5: We had drawn like this, she came to near us and she told us be more explanatory, explain more but we didn't listen her.

R: Yes.

S5: She told us redraw but we continued as it is.

Interview example 12

S15: Firstly we started with liquid phase, and then with the help of our teacher, we decided to start with solid phase all together.

R: You mean that your teacher helped you.

S15: Yes as a guide to show our path.

8. *Asking a reason for seeking an explanation*

   Students were expected to make a reasoned claim about the concepts they were drawing. The teacher began a discussion during the animation creation process by questioning students about the rationales of their drawings. In Example 31, the teacher asked the reason for gas particle distribution and confirmed S6's answer.

Example 31:

T: (Figure 4.3.14) Why it is more spread out?

S6: Because the spaces between particles increased. Gas matter doesn't have any definite volume.

T: When the spaces between molecules increased, the volume is increased too.

S9: Yes

In Example 32 (Figure 4.3.22), the teacher again asked for the reasoning behind the distribution of solid particles and S24 answered. By asking these questions the teacher was able to learn about her students' engagement with their own representations

Example 32:

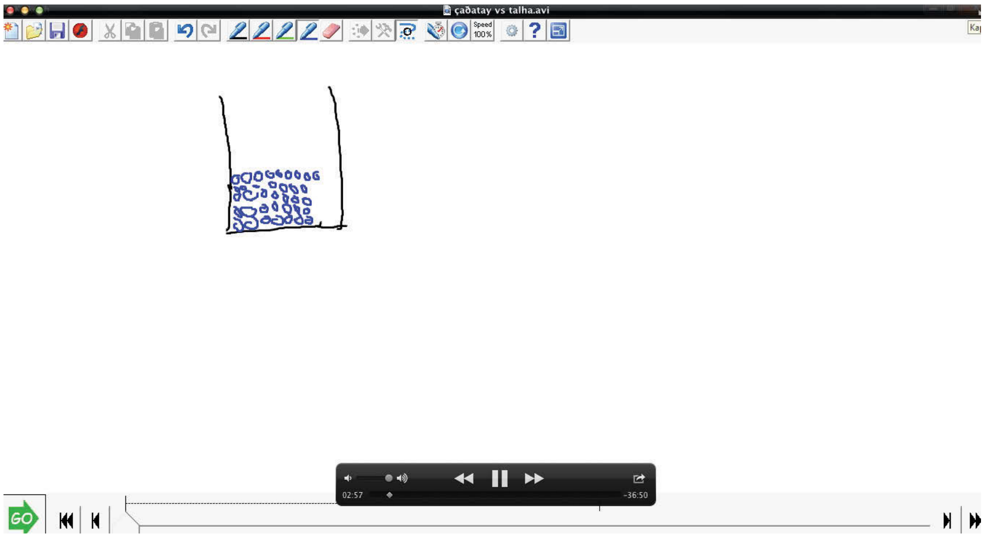

Figure 4.3.22: S12 & S24's first drawings of solid particles animation

T: Why did you draw them very close?

S24: Because of the less spaces between solids.

T: Hmm, OK.

S24: Because there shouldn't be any spaces between particles.

9. *Providing misleading comments*

The teacher twice inferred wrong information – to S6 & S9 (Example 33) and S4 & S7 (Example 34). In Example 33, while the spaces between molecules were increasing, the size of particles was also changing. However, the teacher gave positive feedback to the whole animation by saying 'Very good.' It was unclear why the teacher did not discuss the change in the particle size. She might have been listening only to their verbal explanations, which were conceptually correct, rather than watching the animation.

In Example 34, the teacher emphasised that there were spaces between liquid particles even though this is not true. S4 also confirmed the teacher's wrong guidance by saying that 'they (liquid particles) are going further away'.

Example 33: T: (Figure 4.3.21) Can I watch from beginning?

S9: We showed heat in here; the spaces between molecules increased and turned to liquid. They have spaces between molecules.

S6: We showed heat again

S9: It turned to gas phase.

T: Ooo it is very good.

S6: Irregularity increased.

Example 34:

T: (Figure 4.3.13) They go further when they turn to liquid phase?

S4: Yes they are going further.

S7: But the highest irregularity will be in gas phases.

S4: They will be really further in gas phase.

Surprisingly, in the interviews Groups 7, 9, 10 and 11 claimed that the teacher did not support them at all. These students had difficulties in understanding concepts. The teacher agreed that she did not support some groups. She explained that she helped the groups who had difficulties in the concept. Students' interviews showed that students who had more comprehensive understanding of concept claimed that the teacher supported them and the teacher support was important. In addition, when the researcher asked the teacher about her support the teacher had thought that it is necessary. She thinks that the teacher is a power in the class and helped them to correct their misconceptions while students were drawing. 'If I were not there, they might correct their misconceptions when they watched the expert animations but they might not too. I helped them while they were creating animations, I mean while they were thinking, I helped them to think differently and more conceptually.'

Interview example 13

Group 7

R: Did your teacher help you or did you create everything alone?

S22: She didn't come to near us for help.

S23: She didn't help

S22: We didn't get any help.

Interview example 14

Group 9

R: Did your teacher help you in the process?

S13: We learned with animation.

R: No no while you were drawing?

S13: Yes we heard many times about solid, liquid, gases

R: I mean that when your teacher came to near you and asked you some questions.

S14: Actually until that time we already finished our drawings.

R: You already finished before and just explained your drawings to your teacher.
S14: Yes.

Interview example 15

Group 10
R: Did your teacher help you?
S24: She didn't help us. She just asked us some questions and we explained our animation and nothing else.
R: If your teacher didn't come to near you, you would still draw same animation?
S24: Yes, same.

Interview example 16

Group 11
R: Did your teacher help you in the process or is it your product?
S25: We drew by ourselves
S20: We drew by ourselves.

Finally, there are comments in the interview about creating/drawing of animations. In the interviews, students were asked: 'If you don't draw and just watch the expert animations, do you think it would be the same for you?' Of 11 groups, 5 groups mentioned drawing something or creating animation helped their learning.

In the researcher's interview with Group 1, S7 and S4 stated that they learned more in drawing their animation and discussion lesson. S7 also explained that drawing their animations helped them to be aware of their inaccuracies.

Interview example 17

Group 1
R: While drawing, I mean not only drawing during the whole process while you were drawing or discussing with your partner or while your teaching was giving you advice or while you are discussing your friends' animation in follow up discussion class? In which one you learned more?
S7: Drawing and discussion class
S4: Same
S7: Because during drawing we realised our mistakes or deficiencies.

In the researcher's interview with Group 7, S22 and S23 stated that doing the animation contributed to the depth of their conceptualisation and meaningful learning. The relevant extract from the interview is shown below.

Interview example 18

Group 7

R: If you don't draw anything and just watch the animation showing the solid, liquid and gas state?

S23: It can't be that much meaningful learning. When we drew, it was more effective.

S22: It stayed in our minds permanently and easily as visually.

S23: Yes it provided retention.

In the researcher's interview with Group 9, S13 and S14 claimed that drawing the animation was the most important part of the process. S14 stated that drawing helped them to realise their deficiencies. When the researcher asked for clarification about how creating their animation helped long term retention of their learning, the response was simply 'Yes' from S13. The students then moved to restate the ways in which it helped them to identify and address their misconceptions as well as to visualise concepts. The relevant extract from the interview is shown below.

Interview example 19

Group 9

S14: Drawing make permanent marks in our minds

R: Creating animation?

S14: Yes

R: Why it is more permanent learning, while you were creating?

S14: We realised that we did wrong, it helped as to be aware of our mistakes.

R: If you don't draw, you can't realise the things you have wrong ideas?

S14: Yes. It wouldn't stay in our minds visually and we will not forget in the future.

R: You mean drawing changed your mistakes when you see the expert animations

S13: Yes

In the researcher's interview with Group 10, S12 and S24 indicated that creating their animation was perceived to be useful for their learning. In particular, they argued that animating with their peer helped then to identify misconceptions. S24 also explained that drawing the animation helped them to visualise microscopic conceptions of states of matter. He commented on the macro level water changing states. He explained that the animation with peer process enabled him to go beyond merely recognising that water changes from liquid to gas (or steam) to think more deeply in the microscopic level. It helped them to show their views and exchange ideas with others, which contributed to students' science understanding. The relevant extract from the interview is shown below.

Interview example 20

Group 10

R: Did you learn while drawing? If we just only drew animation or we just only watched expert animations, would it be same result? First we drew, the showed to each other and get comments make comments and finally watched expert animations. How was this process?

S12: Yes we learned more deeply. Firstly we created something in our minds then we visualise it like beaker and give heat. Draw solid, liquid and gas phases.

S24: Yes useful. We had an opportunity to see our mistakes and we learned that how to make correctly. We made connection between visual and oral and brought them together. We learned how to make; we learned how to program everything. Shortly, we learned everything. You gave us a scheduled and programmed lesson and we followed the all steps.

R: OK I understand. If you didn't draw and if you just watched the expert animations, how would it be?

S24: We are always having experiments in labs. Every experiments covered evaporation, melting from primary school but we were just thinking that steam is occurring and we never see their internal structure (micro level). But in here when we visualised them, we think that how they are moving how they are. We transferred our thinking to there.

R: You transferred the things in your mind?

S24: Yes.

In the interview with Group 11, S20 and S25 claimed that drawing their animation influenced their conceptual learning. They indicated that if they had not drawn and rendered their own conceptions visible then they would not have been able to learn as well when considering the expert animations. The relevant extract from the interview is shown below.

Interview example 21

Group 11

R: If you don't draw, and if you just see the animations you also reach to same result?

S20 & S25: Yes

R: You mean that creating animation doesn't have any impact on your conceptual learning?

S20: No our drawings have impact but we mean that if we only draw then we believe that ours is correct we think may be different. But our drawings contribute to our learning to make them visual.

R: OK you mean that if you didn't draw, you could think that your … thinking is [already] correct. But after you draw your animations and watching expert animations was more useful for you?

S20 & S25: Yes

R: Your thinking

S20: We couldn't express our thinking

R: Animation helped you to express your thinking?

S20: Yes.

The teacher said in her interview that she had suggested that the important part of teaching/learning process was 'animation creation by students'. She explained that she could show an animation and lead discussions about the concept but when students created the animation representation themselves. She said, 'They think and they create animations after thinking. That is why the animations are effective.' She claimed that the discussions improved their thinking as they 'think again' about their own animations, how to create them better and make them more ideal. She explained that they are always thinking when creating their animations; therefore, they learn more effectively the concept being studied. 'Until they do not create themselves like until they get the pen in their hands, everything is blurry.' She explained that students did not have enough conceptual knowledge even in the basic concept of 'states of matters' before the animation creating process. They created animations themselves so they corrected their mistakes by themselves. They critiqued even the expert animations and they were totally right in their critiques.

The teacher signalled her intention to use student-generated animations in future teaching:

> I want to use student-generated animations rather than expert animations because while they were drawing, they started to think and imagine and also think about their imaginations. With the expert animations, maybe they will just watch without deep thinking. When they draw animations, they will give full attention to expert animations to find the match and mismatched properties of expert animations with their own animations.

She also wants to use this whole animation process for her other students:

> I wish we'd intervened with this animation creation process with my Years 9 and 10 students, too. I saw that students are getting deep understanding about concepts when they created [animations]. I've learned the program now and have an idea of the whole learning process. I will try the same process with the Years 9 and 10 students. I really think that animations contributed to students' learning'.

4.4. Follow-up class discussions (Phase 3 and Phase 4)

4.4.1. Overview

After the students created their animations, there was a follow-up discussion lesson in two different class sections (11-A & 11-B). In each class section, the teacher followed the same procedure with two phases: Phase 3: discussion of student and expert animations, Phase 4: reflective discussion on the whole process.

In Phase 3, first, students elaborated on their own group's animations. The teacher showed each group's animation to the whole class by projecting it onto the class board so that the whole class could watch each group's animation.

Second, the students were invited to comment on and critique other students' animations. The teacher invited the students to ask questions about anything they thought was unclear in the animation and any parts that were inconsistent with their own ideas. From the animation or the students' commentary about it, the students identified ideas they had in common. They gave positive feedback about others' animations when the ideas represented there matched those they had shown in their own animations. During the critique, the teacher provided feedback to each group. She explained the key concepts in each animation and encouraged the students to discuss their views of them.

In the third stage, after each group's animation had been shown and the discussion completed, the students watched expert animations created in the K-sketch (created by a science teacher) (Figure 4.4.1) as well as animations created in other software programs (Figure 4.4.2). All these expert animations illustrated concepts integral to explaining 'states of matters.'

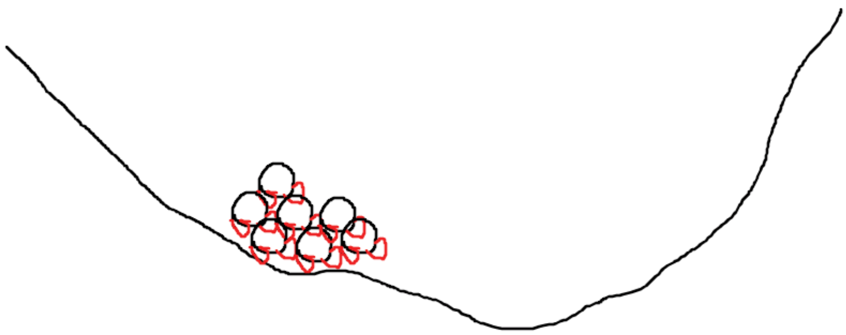

Figure 4.4.1: K-sketch expert animations's liquid phase

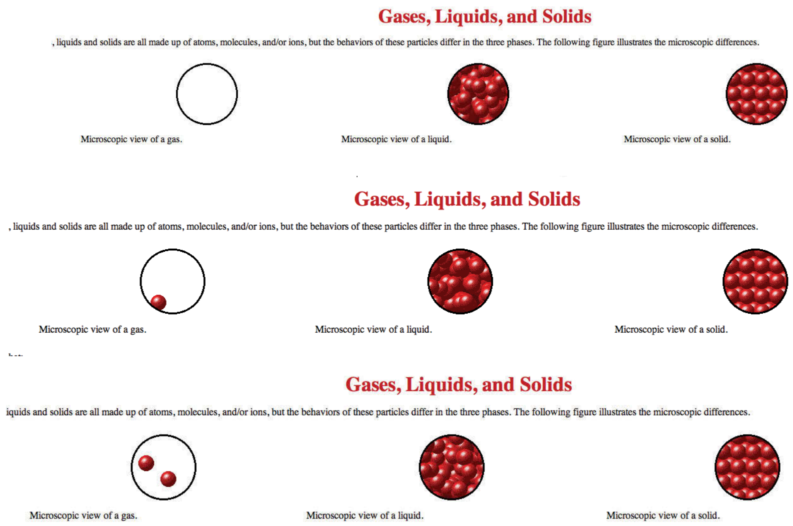

Figure 4.4.2: Solid, liquid gas

In stage four, the teacher led a discussion that provided an opportunity for students to think more about the changes of states and to see the similarities and differences between their animations and the 'expert' animations. When they watched the expert animations, they realised that the changes of state as represented in their own animations were different from those of the expert animations. They identified those attributes of their animations and their ideas about changes of state that were unclear or inconsistent with the expert representations. As they later explained in the interviews, they learned about states of matters by watching the expert animations and comparing their represented views with those represented by experts.

Finally, In Phase 4, the students evaluated the process of teaching and learning, starting from the first lesson, when they learned how to use K-sketch, and ending with the last lesson, when they critiqued both their own animations and those of the experts.

The next section draws on evidence from the video recordings and interviews of with students in classes (11-A and 11-B). The data of Class 11-B are given before the data of Class 11-A according to sequence of intervention.

4.4.2. Student animations (Phase 3)

4.4.2.1 Follow-up lesson class: 11-B

Group 3

Group 3's (S9 & S6) animation was the first group animation projected on the board and discussed by class 11-B. These students did not share their ideas about this animation as freely with their classmates as others did with later animations.

Figures 4.4.3 to 4.4.6 show images from Group 3's animation sequence, which sought to explain the transition from the solid to the gas state. First, they drew the ice cube with a circle representing a zooming view inside an ice cube to reveal the particles. They then showed it being heated up and the particles were enlarged (Figures 4.4.3 and 4.4.4). The teacher projected the animation on the board and initiated the class discussion by asking questions about the animation. The following dialogue (lines 3 and 5) shows that when the teacher asked S5 a general question about his perception of the animation, S5 responded in general terms without any detailed comment on specific parts of the animation.

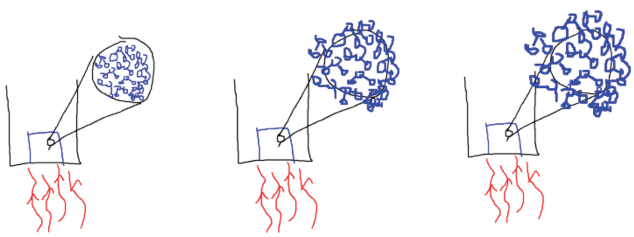

Figure 4.4.3: S6 & S9 animation solid state

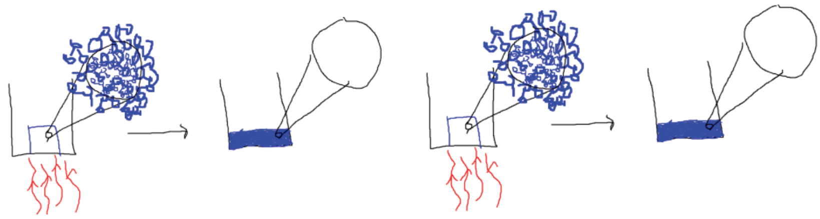

Figure 4.4.4: S6 & S9 animation enlarged solid particles

1. T: Let's watch S9 and S6's animation. How is this animation looking?
2. S5: It looks very good.
3. T: What is very good? Which parts do you like most? Why are you thinking that this animation is good S5?
4. S5: Could you restart the animation please?
5. T: What happened? Which part (of the animation) do you like? As shown in the following extract, S7 then commented on the animation by saying which parts of it she liked in the animation. The teacher then outlined key features evident in the animation that related to a scientific explanation of change of state. She tried to promote a deeper analysis of the animation in the discussion by asking how to make this animation ideal (line 7).
6. S7: From solid to gas the arrangement of particles changed clearly.
7. T: From the solid state to gas state they are well separated with no regular arrangement. In the gas state volume increases because of no regular arrangement. Do you think that this animation ideal? Is this animation ok? How can we improve this animation? What can add to or change in this animation to improve it?

In response, S9 and S6 contributed an evaluation of their own animation. S9 critiqued his animation technically rather than conceptually (line 9). Specifically, he commented on the position of the objects in the animation, the rate of change of the image, rather than any underlying characteristics of states of matter, per se. S4 and S7 also commented that they did not understand the last movement in the animation. S9 replied to S4 and S7 briefly, saying only that the material was turning to gas. S6 elaborated on the explanation conceptually (line 13), but S6's explanation was not consistent with what was shown in their animation. Notably, in the animation a gaseous state could not be seen (Figure 4.4.5). The animation was still showing a liquid state, as blue water. As well, the particles were not moving faster than in the liquid state (Figure 4.4.6); they were just becoming larger. After S6's explanation, no one asked any questions about the animation, such as why the particles were enlarged. Other students may have thought that group 3's explanation was accurate, but the explanation they gave was not consistent with nor did it match with this group's animation because they commented on gas in their explanations but they did not draw a gaseous state in the animation.

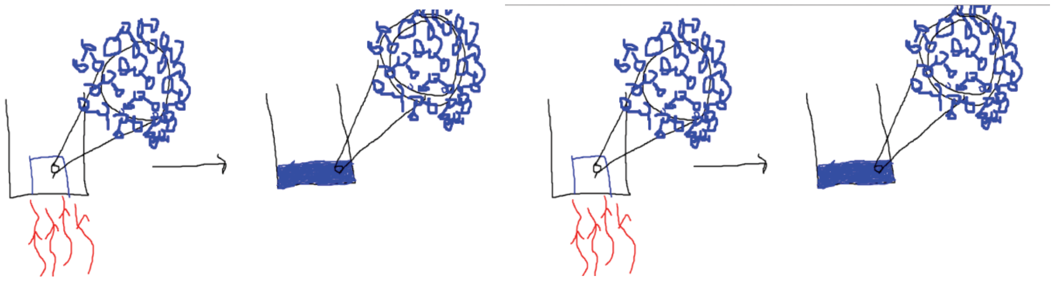

Figure 4.4.5: S6 & S9 animation solid to gas state

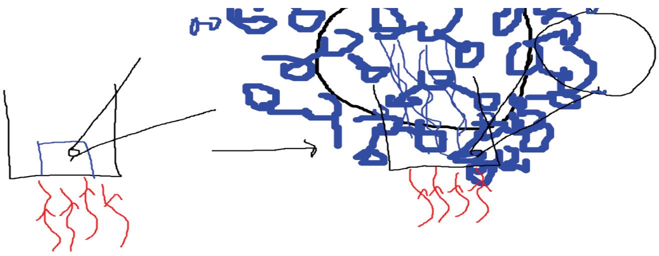

Figure 4.4.6: S6 & S9 animation enlarged gas particles

8. S7: Transitions should be changed.
9. S9: Instead of sudden shift from left side to right side in transition of physical states, the gas should be appear straight on the left (Figure 4.4.5)
10. S4: Actually I don't understand this last movement? (Figure 4.4.5)
11. S7: Yes what is this?
12. S9: This is gas. It is becoming gas.
13. S6: They are moving faster and their energy is increasing and they are evaporating and their regular particle arrangement is decreasing from liquid to gas.

Even though the students were not satisfied with S6 and S9's explanation of the part of the animation that showed a change in the size of particles, they asked no further questions and the discussion stopped. The teacher did not promote further discussion to address the different ideas evident at this time. It was unclear why the discussion did not proceed when there was uncertainty or disagreement. It might have been that the teacher chose not to, or was unsure of how to progress the discussion, or the students simply may not have wanted to discuss it further. Since it was the first animation, both teacher and students might have anticipated that subsequent animations would allow points of difference to be clarified. Notably, data from the interview with this group indicated that it was only one of two groups that considered their animation accurate and requiring no change after the class discussion phase. This group only recognised the need to improve their animation after they viewed and discussed the expert animation.

Group 3's interview after follow-up discussion class

After the follow-up discussion lesson was completed, each group was interviewed by the researcher about the teaching/learning process. In these interviews, nine out of 11 groups spoke positively about follow-up discussion class, with the other two groups mentioning it. In the interview, students were asked: 'Which part of the animation creating process was the most useful for you and what did you learn?' Of the 11 groups, 10 groups mentioned learning about spacing between particles in a liquid state. They were all satisfied that they had learnt a more correct view of the arrangement and movement of particles. They explained that prior to the animation lesson sequence (follow-up class) they were not aware that liquids do not have spaces between particles.

In the researcher's interview with Group 3, S6 stated that she learned about the spaces between liquid phases after they had watched expert animations in the follow-up class. She also explained that showing her animation to the whole class allowed her to explain to her classmates her thinking about changes of state. Her classmates could understand what she thought when they watched her animation. However, she added that watching the other students' animations was less useful until she watched the expert animations. She had wanted to correct the idea, as represented in her classmates' animations, that there was excessive spacing in some representations of states of matter. Group 3 found the expert animations very helpful after their critique of their classmates' animations. The relevant extract from the interview is shown below.

1. R: What did you learn while creating this animation?

2. S9: Actually we already know.
3. S6: We learned that liquids pass above each other and flow easily from others' animations. We generally transfer our knowledge to animation, so it is better for the people who watch our animation.
4. S9: In the professional animations, I learned more about the movement of particles in liquids than their spaces.
5. R: What was the most effective thing in this all process?
6. S9: There is no space between liquid particles.
7. R: Was the discussion lesson useful? You saw your classmates' animations, and you made comments.
8. S9: I think it was useful.
9. R: When you saw your classmates' animations, did your ideas change?
10. S6: If I thought that my classmates' animations were correct then I could learn the concept wrong or different from correct. After I saw my classmates' animation, watching professional animations was very useful. They helped me to make clear something in my mind.
11. S9: Yes, watching expert animations taught me more things than watching my classmates' ones.

Group 2

Group 2's (S1 and S8) animations were shown on the board. The teacher initiated discussion by highlighting selected features of the students' animation and some students talked about it. S5 compared the ideas in Group 2's animation with his group's own animation. He claimed that the spaces between solid, liquid and gas particles were accurate in Group 2's animation, which was on the board. He claimed that he also had similar concepts in mind (see extract below). However, when the class watched S5's and S3's animation (Figure 4.4.10), they could not see any of the changes in spacing of particles between the solid, liquid and gas states that were evident in Group 2's animation.

S5 claimed that he and S3 did not show a change in the spacing in their animation because they could not use the 'save button' properly in the software program. This explanation seems unlikely because S5 and S3 had used the save function on numerous occasions in producing their animation. Hence, there is some uncertainty in interpreting this exchange of ideas because S5 may have changed his thinking about spaces after watching his group's animation. Although he may be claiming that he could not use the save option in the software program, it seems more likely that watching Group 2's animation resulted in a change to his ideas.

1. T: They put spaces between particles. They show solid to liquid state.
2. S5: It is very logical actually we were thinking like this too but couldn't save it.

Figure 4.4.7: S1 and S8 space arrangement

The teacher continued the class discussion by asking questions about the spaces between particles. In this part of the discussion, shown below, the teacher explained some key points to the students about the animation shown in Figure 4.4.7. First, she asked questions to help students think about the spaces between particles and the distribution of particles in each state. When she received an answer from the class, she continued with further questions about the particle spacing. Many members of the groups responded in similar ways.

3. T: The spaces between molecules should be increased more?
4. Class: Yes.
5. S9: Why did they (S1, S8) decrease the number of particles?
6. T: (Teacher replying to S9's question): Because some of the particles escape from beaker when they go to gas phase.
7. T: Did they try to show particles in the microscopic level in this part of the animation (pointing to the paused part of the animation shown in Figure 4.4.7)?
8. S8: Yes
9. T: They increased the spaces between particles.

With the teacher's encouragement, the students critiqued Group 2's animation in terms of their conception of differences in the spaces between particles in different states of matter. As shown in the extract below, the teacher also instructed them on how to improve the animation. S9 started with positive feedback and then continued with comments on how the animation was inadequate or could be improved. S9 explained that the representation of the molecules themselves should not be changed; they should stay the same during phase changes because their structures remain the same throughout a physical change. S9 agreed that the spaces between particles were shown in the Group 2's animation. However, the teacher disagreed with S9's feedback about the spaces between particles (line 13 below). The teacher recognised that the spaces between the particles in the gas phase were too small in comparison to the spaces shown in the liquid phase. She wanted to correct this representation showing inadequate spacing in the gas and she explained to the class how the spaces between different phases should be shown in this animation.

The teacher then encouraged the class to explain how they could create an ideal animation. The students recommended ways to improve the animation. The relevant extract from this discussion is shown below.

10. T: What do you think how can we improve this (S1/S8) animation?
11. S9: I think when we heat; the number of molecules should remain same.
12. T: We observed that number of molecules was decreasing?
13. S9: Spaces between molecules are good but if they don't change the molecules, it could be better animation.
14. T: Actually, they couldn't show the spaces how they wanted to.
15. S9: Yes
16. T: They couldn't show the difference between liquid and gas particles in terms of spaces. Gas and liquid look like similar.
17. T: What else we can add to this animation. Should we replay the animation? (They watched animation again)
18. S9: They couldn't show how we give heat.
19. T: Yeah, to change state, particles need heat.
20. S6: Instead of having separate frames for each state (solid, liquid, gas), they could show all the changes in one screen frame together.
21. T: Yes. We could see all the changes together (in one continuous animation) and, of course, matter cannot change state without getting heat.
22. S7: Yes, transitions from one stage to another not forward. (S6 and S7 are talking in the same time).
23. S9: If they increase the speed of animation maybe we could see the transitions better.

The students and the teacher engaged in an ongoing assessment of Group 2's animation. S6 realised that particles of matter were shown as changing in this animation, but the teacher wanted to emphasise for the class that the structure of molecules does not change during physical changes of states. The teacher focused on S6's questions and asked the class if the structure of molecules changes during physical changes of state. The class laughter indicated to the teacher that the class probably knew the correct response to this line of questioning. She wanted to make sure that all students understood that the structure of particles did not change and to clarify this for the Group 2 students who had created the animation (Figure 4.4.8).

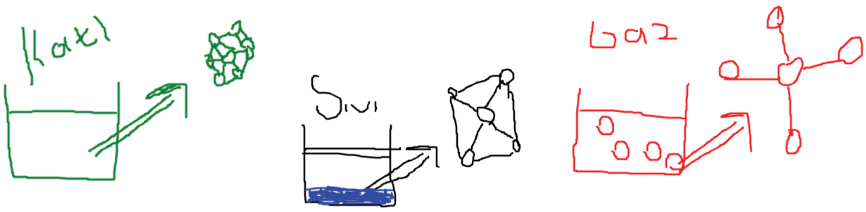

Figure 4.4.8: S1and S8 structure of matters in animation

24. T: But in this part, the visualisation is better.
25. S9: It is better than ours.
26. S6: Compounds are changed over there (pointing to the part of the animation shown in Figure 4.4.8)? (Class laughs).
27. T: Yes, but when matter changes its states, physically, the structure of particles?
28. Class: no, no, no change.

The teacher wanted to check on Group 2's reaction to the discussion about their animation. She tried to clarify what they were thinking about the structure of particles by asking them questions (see extract below). She also made constructive comments about their animation. She mentioned that the changes in the shape and size of the particles, which they had shown in their animation, were a result of their difficulty in drawing identical particles by hand in K-sketch. Thus, she was distinguishing an accidental from an intended mismatch between an important attribute the animation and the students' conceptualisation.

29. S1: No no no change in their structure.
30. T: Yes, no change, I think you drew particles as different from each other in each state just because you couldn't draw them the same in the program?
31. S1: Yes, yes, because we couldn't draw it properly in the animation program.

32. T: The compound turned to a totally different compound just because of ineffective drawing.

In Group 2's discussion, we can see that there was no mention of bonds between particles in each state. However, as shown in Figure 4.4.8, they tried to draw different bonds. They had mentioned these bonds when they were discussing their ideas with each other, while they were drawing the objects in their animation but they did not talk about bounds with their classmates.

Group 2's interview after follow-up discussion class

Group 2 was one of the groups that spoke positively about the follow-up class, with both group members saying it was useful. In addition, they claimed that after the expert animation they realised that liquid particles exist with similar spaces to solid particles. This idea about spacing differed from their previous view, as they had represented it in their animation.

R: Did you learn something while creating animation? What did you learn in the whole process from discussion with your partner, creating animation to discussion class?

S8: In the whole process, I learned about spaces in liquid phases. When we watched real animations, we saw that solid and liquid phases have same spaces between particles but we had drawn larger space for liquid phases.

R: The discussion in class was useful for you?

S8: Of course

R: If you just drew animation and finish the learning process, could it be as useful for your learning?

S8: No, it can't be that much useful without discussion class.

S1: Yes useful, we watched our own animations and our friends' animations we made comments.

Group 1

Group 1's (S4 & S7) animation (Figure 4.4.9) was the third to be shown on the board. The teacher initiated the discussion and the students explained their views about this animation. S4, tried to explain the parts of their animation with which they were dissatisfied. The relevant extract from the conversation is shown below. The teacher noted a feature of the animation that was good (line 1) and told the class that the 'particles are clear'. S4 agreed with the teacher's comment and explained that they had paid particular attention to drawing the particles. The teacher continued with the word 'but', which shows her uncertainty about the animation. S4's agreement with the teacher shows he was also aware that there should be something more in the animation (line 4). Even though he got positive feedback from S3 (line 5), S4 was not satisfied with his group's animation, and he contributed a self-evaluation of it (line 6) with his comment on the lack of motion in each particle.

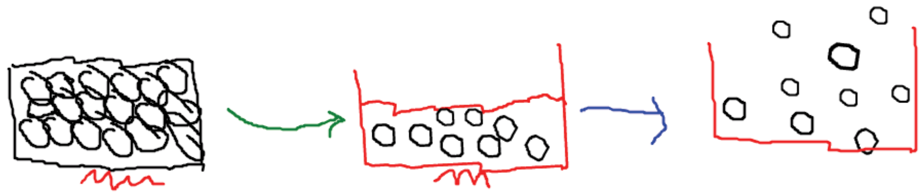

Figure 4.4.9: S4 and S7 animation

1. T: Yes they showed particles very clear.
2. S4: Actually, we only focus on particles.
3. T: It looks good but….
4. S4. Yes, yes, I think so.
5. S3: I think it is very good.
6. S4: If we have give motion to each particle, I mean if we show each particle's own motion, it would be better.

After S4's evaluation of his group's animation, the teacher added key points about the particles' movement in the solid, liquid and gas state. In the following extract, she explains the particles' movements as a vibration in the solid state, sliding past each in a liquid and flowing easily in the gas state:

7. T: For example, in here (pointing solid state on the board) you can vibrate particles. In that one (pointing liquid state on the board) you can show that particles slide past one another. You can also give different motions to gas particles, such as flowing easily or spinning etc.

The teacher promoted discussion among the other students by asking them for their ideas following her feedback. In this animation by Group 1, the particles in the solid state were shown in a more regular pattern than the previous animations (Groups 2 and

3), which had already been shown. S9 made a comment on the regular pattern in the animation. S6 claimed that even though the idea was clear in the animation, it was an inadequate animation (line 11 & 13). Having previously realised and explained an inadequate part of their own animation, S4 agreed with S6's comment (line 14).

8. T: S9 and S6, What do you think about this animation? What is shown well and what is not shown?
9. S9: Good thing is that they drew the particles in a regular pattern.
10. T: Their drawings are really done meticulously.
11. S6: I think the best thing in this animation, the idea is clear, whatever they want to show it can be seen.
12. T: Yes, the animation is really showing what they tried to explain.
13. S6: Yes it is good we understand but not exactly sufficient.
14. S4: Yes I agree with you.

The teacher continued to encourage class discussion by making positive comments about Group 1's animation. She mentioned that it was the first time they had created an animation, so some inadequacy in the representation is understandable ('ignorable'). Even so, she emphasised the importance of motion in animation. Both S7 and S4 were also aware of an inadequacy in their animation. S7 mentioned adding vibration to particles (line 16), which was different from S4's previous explanation (line 6).

15. T: This is our first animation so we can ignore them but in terms of motion to make animation more attractive???
16. S7: We could show vibration.
17. T: Yes, yes this was my idea. (class laugh)

As shown in the next extract, the teacher continued to encourage discussion. S6 drew attention to a different feature in the representation of the concepts – the colour of particles. The teacher asked a guiding question of S6 (line 20) to make sure that S6 understood that the colour of particles should remain the same throughout changes of state. Before responding, S6 thought for a while about whether or not the colour of molecules changes during the physical change of state. She explained that water is blue, therefore the particles should be blue, but each particle's colour should not be changed because that would imply they had turned into different particles.

There is some uncertainty in interpreting this exchange of ideas because S6 may have changed her thinking about changing the colour of particles after the teacher's guiding question (line 20). Even though S6 realised that all particles should be same colour, she was thinking about the macro and micro levels in relation to the use of colour in the animation. She explained that water is blue at the macro level but that each particle should stay the same colour at the micro level. In other words, at the same time as she was creating particles at the micro level, she was thinking of how to show the colour of water at the macro level. Here we see that interpretations of the apparent colour of water, setting aside how it may vary in different circumstances, are intruding on conceptions of particles in the states of matter. As shown in the next extract, a difficultly is being experienced in separating the appearance at the macro level from the representation of particles at the micro level.

18. T: What else could we do for this animation? Yes girls, what do you think?
19. S6: We could do colourful particles.
20. T: If we make particles in colour, what changes? Should we do each of the particles with different colours, or when is going to liquid? (This comment referred to the images showing particles with different colours in different states.)
21. S6: I mean, like water is blue, otherwise how come each particle comes in different colour then its structure changes.
22. T: Yes, otherwise its structure would be changed.

Group 1's interview after follow-up discussion class

In Group 1's interview with the researcher (see extract below), S7 explained that the discussion class helped their thinking about states of matter. While they were explaining the features of their animation that were consistent or inconsistent with their own thinking and the features of their classmates' animations, they realised their own deficiencies. S7 claimed that while they were watching the expert animations in the follow-up class, there were some moments when they said, 'Oh yes, we get the idea.' In addition, while they were watching the expert animations, they learned about the movement of particles in a liquid state and how they pass among each other and they flow easily. While they were discussing the animations, they thought more about the concept. This helped them to become aware of deficiencies in their conceptions of states of matter, particularly about spaces between particles in liquids.

S7: … in the discussion class we thought more deeply and we said, ‘Oh! Yes we shouldn't do this again.’ We discussed our misunderstandings or lack of some points. The discussion part is more important but while we were drawing, we also learned many things.

S4: Yes, exactly.

R: Could you give an example?

S7: I want to give the same example. I was thinking that the spaces between liquid particles are really increasing, but I learned that in the liquid phase, they are only flowing, and their sliding in the movement is increasing.

S4: Yes exactly.

S7: I learned this.

R: You mean that you were saying, ‘Oh! I get it’?

S7: Yes I said

S4: Yes me too.

R: Ok I understand

Group 4

Group 4’s (S3 and S5) animation was shown on the students’ laptop instead of the board. They could not transfer it to the board because of technical problems with their hard drive. The whole class came close to S3’s and S5’s desk and commented on Group 4’s animation. This was the last animation shown in this class (11-B). Students shared their ideas with their classmates more freely for this animation than they did with previous animations. Figure 4.4.10 shows images extracted from Group 4’s animation.

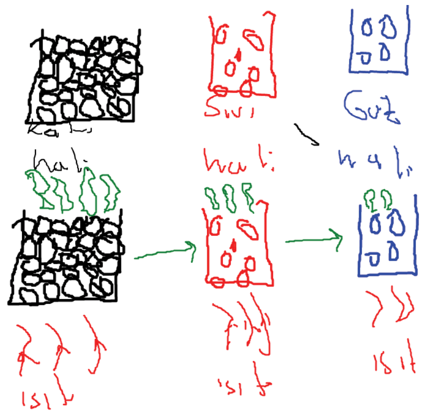

Figure 4.4.10: S3 and S5 animation

The whole class and the teacher watched the animation but they could not get a clear idea of what Group 4 was really trying to show in their animation (lines 8 and 9) even after S5 replayed the animation. With the class silent, the teacher asked Group 4 to explain their ideas. S5 did not want to explain at first and asked S3 to explain, claiming that the animation represented S3's ideas and that S3 should explain it to the whole class. Even so, it was S5 who explained the animation. The relevant extract from the discussion is shown below.

1. T: Who is left? Let's see S3 and S5's art product. Ok. We couldn't open your animation on the board so everybody let's go to near S5 and S3's desk to watch their animation from their laptop.
2. S5: Now you will see a really good product.
3. S7: Yes, I really am wondering about their animation.
4. S5: Are you ready to see our animation?
5. Class: no, no, not yet.
6. T: I also really want to see your animation. Just wait.
7. S5: Ok now. Let's watch it.
8. Class: What is that?
9. T: Let's watch again.
10. Class: silent
11. T: Ok. What did you try to show in here? First we need your explanations, please?
12. S5: S3 you should explain because this was your idea.
13. S3: Silent.

Group 4's classmates then tried to understand the animation by asking questions about specific parts of it that were inconsistent with their own ideas. First, S6 asked about the 'green things' (Figure 4.4.10) in the animation (line 14). S5 replied 'steam', but S6 asked further questions about the liquid state, an aspect of the representation with which she disagreed. S4 also asked about something he either disagreed with or could not understand, questioning why the animation showed steam coming from the solid. All the other students started to laugh, which indicated that the class probably thought that steam does not exist as a feature of a solid state and should not be shown in an animation representing a solid state but the humour used was not sarcastic and classroom environment supportive for student learning. S5 could not give a satisfactory answer in relation to the steam being represented in the solid state. The teacher realised that these features of changes of state represented in Group 4's animation were inconsistent with those of their classmates. Not wanting S5 to be pressured by his friends or embarrassed by his inability to answer, the teacher made a joke, ‘Who is your chemistry teacher?’ (line 22).

14. S6: What are these green things here?
15. S5: They are steam because steam is starting to occur.
16. S7: How are they are becoming bigger? Look they are small now and then suddenly becoming bigger (She is pointing to particles).
17. S5: Umm!
18. S6: But why has liquid got steam?
19. S4: Especially how come steam is coming from the solid?
20. Class: Laughing.
21. S5: Because we are heating from bottom.
22. T: Who is your chemistry teacher?
23. Class: Laughs again.
24. S5: She is one of my favourite teachers.
25. S6: It looks more like solids are evaporated.

The teacher encouraged further discussion by asking the class for their ideas about Group 4’s animation. S6 explained that S3 and S5 drew the particles in the solid, liquid and gas states differently and there were more particles shown in the image of the solid state. S5 explained that they did not want to draw more particles in the solid state. They drew a large beaker for the solid state that was why they had more particles in the solid state. S5 did not mention that some particles were evaporating from the solid state to the gas state, and so they had fewer particles in the gas state. S5 could not explain the change in the representation conceptually (line 28) in terms of the differences in the number of particles or size of particles in the different states of matter. According to S5, the change in the numbers of particles shown in their animation did not represent any conception of the change of state but was simply a by-product of a random decision about the size of the container they drew.

26. T: Could we watch again but play it little bit slowly? What we understood might be different from what they tried to explain. First we tell them what we understand from their animation.

27. S6: I understand that particles are different in here because they are in different colours. And when they heat all of them, there are more particles in solid states than other states.
28. S5: I just drew it like that because this beaker is bigger.

The students continued to ask more questions about spaces between particles in Group 4's animation. S5 implied that the changes in size of the particles, which they had shown in their animation, were a result of their difficulty in consistently drawing objects of the same size. Thus some variations in the animations were accidental and random products of their lack of ability to draw rather than an intentional rendering of their conceptions.

29. S6: Everything was finished very quickly. That is why it is hard to understand.
30. S4: The space between gas and liquid particles are looking like same.
31. S5: S4 you don't know my drawing ability.

The teacher invited the students to ask more questions about aspects of the animation that were inconsistent with their own ideas. S9 explained that Group 4 had similar ideas with their (S9 and S6) own ideas, but S3 and S5 had some uncertainty in interpreting their ideas for the class. The teacher requested further explanation from S5 (line 35), but S5 did not want to explain the animation because he claimed that he also did not understand aspects of what he had drawn (line 38).

32. T: What else?
33. S9: I think what they tried to draw is the same thing you requested from us to draw.
34. S7: I think the thing what they tried to explain is same as ours but…
35. T: Ok S5 you explain it for us.
36. S5: First we heated solids. Then steam has occurred top of it. Then something happened. Then we heat the liquid like this.
37. T: We don't understand. Please explain again
38. S5: I don't understand, too.
39. Class: Laughs
40. T: What did you try to draw, just explain this?
41. S5: First I heated solid.
42. T: Ok.
43. S5: After that?

The teacher tried to promote a deeper analysis of the animation by asking guiding questions of S5 about the changes of the matter in solid, liquid and gas states, when they were being heated (line 48). S5 could not explain his ideas freely without the teacher's structured questions. His explanation was limited to short replies to each of the teacher's questions.

44. T: What happened while changing from solid to there?
45. S5: Where?
46. T: I mean why you have two form (showing top and lower images in Figure 4.4.10)?
47. S5: To see more clear. These are substances and we heat them here.
48. T: It means when you heat them, they are still the same? This solid is still solid, liquid is still liquid and gas is still gas?
49. S5: Yes solid, liquid and gas again.

It is unclear why S5 responded this way. It might be that he did not want to discuss further or he was anticipating further discussion that he would not clarify his own ideas clearly. As the conversation progressed, the teacher came to understand the students' ideas more clearly (line 50). The idea in Group 4's animation was different from the other groups' animations. They did not keep the substance constant and show changes within this substance as it changed state. Rather, in their animation they showed three different substances when they represented each different state of matter. They showed the effect of heating each of these substances separately. However, the only change that they showed was 'steam' (buhar) or 'gas' (gaz) emanating from each substance on being heated. They seemed to equate steam with gas, using the terms interchangeably. They showed no changes in the movement of particles.

50. T: Ok I got the idea now. In the beginning they are showing a solid, liquid and gas separately. After that, they (S3 and S5) heated up each matter in each state separately and they are showing what is happening in the each state.

After the teacher had understood what S3 and S5 were trying to show in their animation, she asked S5 about the parts of the animation that were inconsistent with their actual ideas. S5 claimed that their animation was not yet finished because there was not enough time to complete it (line 52). The teacher asked a further question in line 53 to explore their thinking. S5 explained the arrangements of particles in terms of spaces in the second row of their animation (Figure 4.4.10). The teacher asked one more question to clarify whether the comment regarding ‘more spaces’ between particles, which had been mentioned in S5’s explanation (line 54), related to the all states of matter or only to the gaseous state. S5 thought about it for a few seconds. First he said, the correct answer, ‘No.’ Then he thought for a while again and said, ‘Yes, yes.’ He implied that he would draw more spaces between all particles. S5 could not give a scientifically correct explanation about spaces between particles for different states or identify the correct state with the teacher-guided question (line 56). The purpose of the teacher’s question was to provide structured support assist with the development of the correct science concept. The discussion ended when S5 stopped replying to his teacher.

51. T: It is good but there is not much difference between first and second (pointing to before heat i.e., the top three images and after heat drawings i.e., the lower three images shown in Figure 4.4.10).
52. S5: Yes because we were trying to draw the third one (they have top and lower images) but the bell rang.
53. T: Ok if you had time to draw third one, how would you draw it?
54. S5: We were planning. There should be more space between the particles and all would be in the gas state.
55. T: Between all of them? Solid, liquid, gas?
56. S5: No. I mm. Yes, yes. All of them would be like that.
57. T: Ok.
58. T: I think that you tried to show things with transitions. How should be, first solid, liquid, gas?
59. S5 (No reply)

Group 4’s interview after follow-up discussion class

Group 4 was also one of the groups that talked positively about the follow-up class. S3 claimed that the comparison of the ideas in their animations with those of the expert animations helped their learning. To understand how it helped their learning, the researcher asked a further question, ‘Did you think more about your animation?’ S5 replied that he realised which parts of their animation required both improvement and better explanations.

R: While you were drawing, did you learn something or not much about things?

S5: Of course we learned something.

R: What did you learn?

S5: We saw physical transition between different phases of matter as live (as it really happens).

R: Which part of the whole process, not only drawing but also watching others' animations or experts' animations or in discussions helped your learning more than other parts?

S3: We learned better when we compared our animations with expert animations.

R: In discussion class, you saw other animations. Did you think more about your animation?

S5: Yes, we realised that we could explain our animation better and we can improve our animation.

4.4.2.2 Follow-up lesson class: 11-A

Group 5

Group 5's (S15, S16 and S17) animation was projected on the board. This was the first animation to be shown and discussed by Class 11-A. This group differed from the other groups by having three members. Figures 4.4.11 and 4.4.12 are images from their animation sequence showing the changes from the solid to the gas state. Group 5 first drew each state in the macroscopic level (Figure 4.4.11) and then an arrow representing a view inside of an ice cube to reveal the particles in the solid, liquid and gas states (Figure 4.4.12).

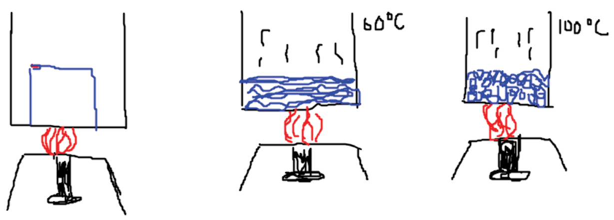

Figure 4.4.11: S15, S16 and S17's animation solid, liquid and gas states

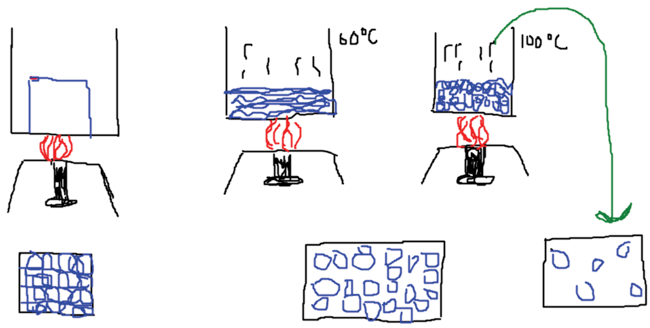

Figure 4.4.12: S15, S16 and S17's animation, particles

The teacher projected the animation on the board and initiated the discussion by encouraging S17 to explain the animation. She explained that her group heated the particles, turning them from solid to liquid at 60°C, and then to the gas state at 100°C. She also explained the arrangement of particles in the solid, liquid and gas states. She thought that there were tiny spaces between particles in the solid state, and those spaces were increasing from solid to the gas states.

1. T: Firstly, S17 should explain us what they tried to draw then we talk positive and negative parts of their animation.
2. S17: My dear teacher, firstly we heated the ice.
3. T: Yes
4. S17: Then the solid particles are turning to liquid particles. It is at 60°C.We continue to heat until 100°C and then it is boiling. In the first one, the spaces between particles are ignorable. In the second and third images, there are more spaces than the first one. We showed more spaces in the third one that is the gas phase.
5. T: The spaces between particles are more?
6. S17: Yes.

After this explanation from S17, the teacher instructed the class on how to improve the animation. S24 commented on the animation not showing particles. The teacher agreed (line 9). Even though the teacher agreed with S24 about the representation not showing particles, Figure 4.4.12 shows that Group 5 drew particles linked by an arrow to the macro view. S21 commented on the level of water. The teacher explained that the level of liquid should decrease because of 'evaporation' (line 11). The teacher then tried to promote discussion with the other students by asking them if the animation was inadequate or could be improved. S17 talked about technical aspects of the animation, suggesting arranging time frames differently in their animation and suggested that the transitions from solid to liquid state and liquid to the gas state were too slow and the shift to the view of particles was too fast. It was hard to see the movement of particles, shown in the lower section of Figure 4.4.12, because the animation only appeared briefly on the screen before transitioning to the next step. After S17's comment, S15 said that he had arranged the transition timing in the animation (line 13).

7. T: What is shown well and what is not shown well in your classmates' animation? What do you recommend to improve this animation?
8. S24: If they drew in particles, it would be better.
9. T: If they showed particles, yes.
10. S21: Should there be less water in the second beaker?
11. T: They should decrease the water level because of evaporation and increase the steam. What else? What do you add to this animation? If you drew this animation what would you add? What part is inadequate? How could we make this animation more attractive and original?
12. S17: by arranging time frame…
13. S15: Look! I arranged the time frame again.

Even though the teacher tried to promote further discussion about how to improve the animation, the class did not make further comments and the discussion stopped. This pattern in the class discussion was similar to the pattern in 11-B in that the discussion of the animation that was shown first was shorter than the discussions of later animations. Moreover, even though Group 5 (S15, S16 and S17) showed the particles in their animation, they did not respond to S24's claim that particles were not shown. Hence, it is difficult to understand Group 5's reaction to the discussion about their animation. They were interviewed about their animation after the follow-up discussion class.

Group 5's interview after follow-up discussion class

Group 5 spoke positively about the follow-up class. Like the other groups, this group was satisfied that the sequence of events with the animations had allowed them to learn better the arrangement of particles in the different states of matter. They explained that, prior to the follow-up discussion class, they had not been aware that liquids do not have spaces between particles. The lesson sequence also influenced their view of how 'hard' chemistry is. By the end of the sequence they had come to the view that chemistry was less difficult than they had previously thought. S16 found the follow-up class lesson useful because she learned better when she visualised things. However, in the interview, Group 5 did not mention the discussion with their classmates about their own animation.

R: (Through the sequence of events) What did you learn?

S15: I learn that the chemistry is not as difficult as I was thinking before.

S16: Yes I also learned this.

S15: I was wondering about that, how people make cartoons (Commenting on the way animations are produced while smiling giving the impression that making an animation was enjoyable.).

R: You mean it was enjoyable?

S15: Yes

S16: I have a better grasp with visualisation about the concept that I had already known.

S17: We thought that there are spaces between liquids but it is like almost no space. We learned it.

R: Anything else?

S16 and S17: (No reply)

Group 9

Group 9's (S13 and S14) was the second of Class 11-A's animations to be shown on the board. Figure 4.4.13 shows images extracted from Group 9's animation. This discussion began differently because the teacher started with a comment (line 3), rather than asking a question. The class laughter could be interpreted as amusement or mild derision, giving a perception that the animation was inadequate. The teacher expressed a negative view about the adequacy of the ideas expressed in the animation by commenting sarcastically on the possibility of a change of state occurring without a change of temperature. S13 explained that they understood that heat was involved as the solid changed state, but they had experienced difficulty with their use of the software. Specifically, they could not save that frame showing heat with the solid. An unintended consequence was that their animation indicated that heat was only involved in changes of state related to liquids and gases. When the animation was shown on the board, there were unclear or incomplete parts, for example, a heat source was not shown under the solid representation but was shown under the liquid and gas representation.

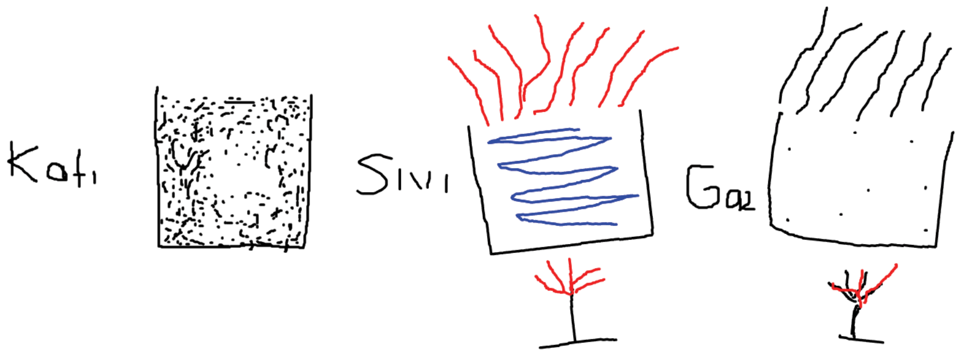

Figure 4.4.13: S13 and S14 animation

1. T: Please everyone should look the board we are talking about your classmates' animation. I am showing S13 and S14 animation on the board now.
2. Class: Laugh
3. T: S13 and S14 are very successful to change the phase of matter from solid to the liquid state without giving heat.
4. Class: Laugh
5. S13: No, no and. Look, there is something under of beaker; it is going and coming back. It is not properly saved.

The teacher asked the group to explain the liquid state in their animation. S13 responded in general terms to the animation as a whole, without any details. The teacher asked S13 about her ideas of the animation (line 8), reminding her that while she was creating their animation she had said that 'the molecules in the liquid state are looking like lines'. With the teacher's encouragement, S13 explained to the class that she thought that liquids were wavy and blurred (line 9). Group 9 was trying to show particles and their motion into gas, with the line showing the particles' motion.

6. T: Yes, they turned from solid to liquid. What is the purpose of showing liquid in that way? Why did you show the liquid like this?
7. S13: It started to evaporate. After a bit, all particles turned to gas because of heat.
8. T: S13 what did you think while you were creating this animation? Could you explain your thinking? You said, 'I am thinking of the liquid material as lines.'
9. S13: We said that there was less space between particles in solid state. There were more spaces in the liquid phase than the solid phase. We imagined that

liquid was blurred and it was wavy like sea [water]. There were also many spaces between gas articles. We imagined it like that.

10. T: You tried to draw the more particles … including motion in the gas phase.
11. S13: Yes.

The teacher continued with questions about how the animation could be improved. According to S24, the animation should be re-created from the beginning because there was no ‘harmony’ in the whole animation. The teacher asked S24 about this inconsistency (line 18) and S24 explained that solid state was looking like a liquid state, the liquid state was looking like solid state, and the transitions were not clear. The teacher agreed with S24 about Group 9’s animation showing the transitions between states.

12. T: What could we change in S13’s animation?
13. S21: The thing which is shown under of solid particles are. I, mm …
14. T: Yes
15. S24: I think it should be created from the beginning.
16. T: Why?
17. S24: Because they are not in harmony with each other. All are incompatible.
18. T: Where is its mismatch?
19. S24: They drew the solid particles as the liquid particles, and liquid particles are looking like solid particles. They could arrange the transitions of particles from one state to another one.
20. T: They could show the relation of particles (for phase)?
21. S24: Yes exactly you are ‘number 10’ (10 out of 10, very good).

The teacher encouraged the class to explain what they could add to Group 9’s animation. Students commented and recommended improvements to it. First, S15 suggested heat be included to show that heat as involved with the solid state, but S13 rejected his comment, insisting that they had already heated the solid state. The teacher did not want to concentrate on this. Both agreed that heat was involved. So it was only a matter of its representation, rather than its conception. The teacher shifted the discussion to the particles. S15 commented on the representation suggesting that the animation of gas particles could be improved, but S18 disagreed and responded specifically in terms of the image of the gas particles, claiming that the large spaces between particles were shown. This comment indicates that S18’s idea about spacing was not different from Group 9's thinking, as represented in the animation. S16 explained his ideas in more detail (line 31) with a comment about the movement of particles rather than the spacing between them.

22. T: Yes, is there anything that you want to add S13's and S14's animation?
23. S15: Firstly, they did not give heat to solid.
24. S14: Don't say they did not give.
25. S13: Look my teacher, heat is going and coming on the screen.
26. T: Yes (pointing that heat on the board). Let's skip it and talk more about particles.
27. S15: They could show the gas particles better.
28. T: They could show better the phases of gas particles.
29. S15: Yes
30. S18: No, it should be like this with more spaces. Otherwise how it should it be?
31. S16: No, I mean the motion of particles.

At the end of the discussion of Group 9's animation, the teacher made constructive comments about it (see extract below). She mentioned that they had transferred their own thinking to the animation and that their thinking was different from others in the class. The teacher's intention here seems to be to convey that the purpose of creating animation is not producing the correct animation but is giving a clear expression and reveal one's own conceptions through animation. Notably, they thought water molecules were similar to sea waves and spread out like waves.

32. T: I think, the most interesting thing in this animation is the imagination of liquid phases.
33. S24: Yes, I think so.
34. T: I think, it is good and interesting because this is just the reflection of your own thinking.
35. S13 thought the liquid particles as water waves and spread out like waves. It is not bad.

After the follow-up discussion class, Group 9 was interviewed and the relevant parts are shown in the section below.

Group 9's interview after follow-up discussion class

Group 9 also found the follow-up class helpful for their learning. S13, in particular, claimed that she learned about solid, liquid and gas states while she was watching the expert animation. She realised her misunderstandings when she had had an opportunity to see differences between their own animations and the expert animations. The relevant extract from this interview is shown below.

S13: Before I didn't know how the solid, liquid and gas states are.
R: How did you learn then?
S13: With animation?
R: Which ones contributed to your thoughts?
S13: We watched one.
R: Which one?
S13: Round particles was moving
R: You said aah I was thinking wrong
S13: Yes
R: You mean drawing changed your mistakes when you see the expert animations
S13: Yes.

In the researcher interview with the teacher, the teacher talked about this group. She explained that S13 had not shown molecules in the liquid phase. If she had not created an animation illustrating her views of the states of matter, the teacher would not have known what S13 was thinking regarding the liquid phase. She also added that if she as a teacher did not address this conceptual problem then the students might have continued with their misconceptions. S13 thought about liquids in terms of lines or waves until Year 11 even though in every previous year the curriculum covers the states of matters. In the animation creation process, her misconceptions came up. The teacher said, 'Therefore, creating animations was very effective [in helping her] to realise students' misconceptions.'

Group 6

Group 6's (S21 and S27) animation was shown on the board. S27 was a new student in this class and he had not attended the K-Sketch workshop in the previous week. He did not talk about their animation during the follow up discussion process. He spoke very little with and made very few contributions to his group while they were creating the animation. When the teacher wanted to show Group 6's animation to the class, S21 did not want to open it to show the class.

1. Class: Please show ours (S18), ours, ours (S24).
2. T: Friends (Angry call to class) Be silent. (and she try to open S21's and S27's animation)
3. S21: Don't open ours.

Figure 4.4.14 shows images from Group 6's animation sequence, with transitions from the solid state to the gas state. When the animation was projected on the board, S16 made a comment about the sketching of the beakers. She also added that Group 6 did not show particles in their animation. The teacher then engaged the whole class in the discussion and asked Group 6's members to explain their thinking. S21 explained their animation (line 21) but S17 interrupted, commenting, 'They did not apply heat to change state.' S21 responded that they had done so (line 8). The teacher supported S21 and explained that the increasing temperature was shown in the heating of ice.

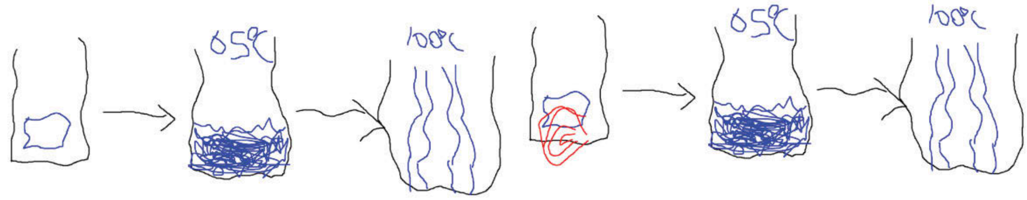

Figure 4.4.14: S21 and S27's animation

4. S16: Their beakers are different from each other and they didn't show the particles.
5. T: What do you think about this animation? Yes. S21 and S27 what did you think?
6. S21: Firstly, we imagine an ice block. It turned to liquid phase when we heated it up and then steam goes to above
7. S17: They did not give any heat.
8. S21: We gave heat but in the right place.
9. T: They increased the temperature and it was showing heat. What about the particles? Yes?

S18 recommended an improvement to the animation in (line 10). The teacher asked specifically about their views about gaseous state. Figure 4.4.14 shows lines in the gaseous phase, and the teacher asked S21 and S27 to clarify their views about these lines. S21 responded that because steam spread into the air as lines, they drew lines in the gas state. This suggests that they are showing the macro or directly visible characteristics of the change of state, that is the steam in the air, rather than the micro characteristics, that is the particles that make up the substance.

10. S18: They should show no space in solid particles and draw (them) closer to each other. Liquids should have less space.
11. T: Did you think the of the gas phase as lines?
12. S21: Yes because it is evaporating to the above line this line.

Discussion stopped after S21's response to the teacher. Group 6 (S21 and S27) was then interviewed, but only S21 spoke about follow-up discussion class.

Group 6's interview after follow-up discussion class

In the interview with Group 6, S21 said she was satisfied that the follow-up class helped her learning. She claimed that she could not have learnt about changes of state without the follow-up discussion class because only there could she compare her group's views with those of the experts. She realised that after the animation lesson sequence she could now create better representations than she had done previously. She also contributed a self-evaluation (line 21). The relevant extract from the interview is shown below.

R: If we don't have discussion class, do you still learn something?

S21: No. We can't learn because if we don't discuss and if we don't compare our thinking with others, we can't learn.

R: You mean it makes difference

S21: Yes, I think it was useful. The program was useful and we saw expert animations it was useful, too.

R: You had the opportunity to compare?

S21: Yes I compared my one with others and I thought that I could make mine better.

R: I see.

S21: How didn't this [feature of expert animation] come to my mind' (Smile). I thought this one for long time [Why didn't I think of this before I saw the expert animation.]

Group 8

Group 8's (S11 and S18) animation was shown on the board (Figure 4.4.15). S21 started by saying there was no motion shown in Group 8's animation. The teacher then asked S18 to explain their thinking in the animation. S18 explained their animation as a whole, with detailed comments on specific parts. He thought that solid, liquid and gas states all had spaces between their particles. These spaces were increasing from the solid state to the gas state. Moreover, all three states of matters could be compressed. To get a clearer idea of S18's perception of compression, the teacher asked whether or not solid particles were compressible. S18 said that they were all compressible. The teacher continued this discussion of compression and asked about the compressibility level of particles in each state. S18 did not talk about solids, but said that a gas could be more compressed than a liquid. The teacher asked again whether or not solid particles could be compressed, but this time S18 kept quiet. The relevant extract from this conversation is shown below.

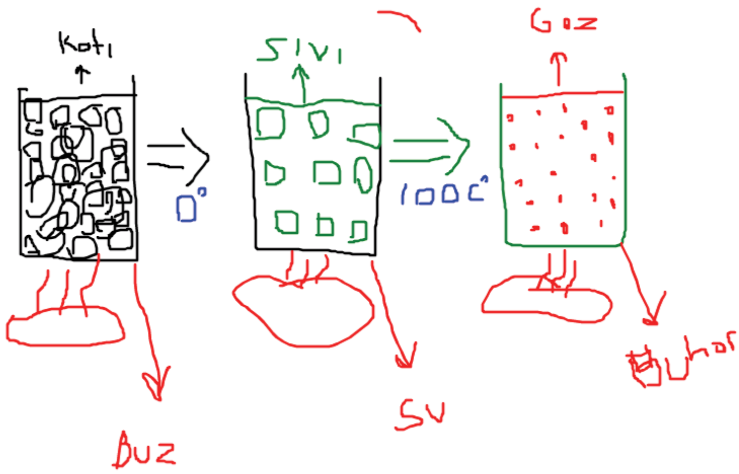

Figure 4.4.15: S11 and S18's animation

1. S18: My teacher, show ours now.
2. T: I'm showing S11and S18's animation. Yes let's watch what they drew.
3. S21: There is no motion, too.
4. T: Yes. You explain.
5. S18: My teacher we showed, solid, liquid and gas phases. The solid, liquid and steam phase of the ice block. We wanted to show that there much less space between solid particles. In liquid more spaces, and gas particles has the highest spacing of all phases and we can compress the gas particles more than others.
6. T: Could we compress solids, liquids and gases?
7. S18: Yes they are compressible.
8. T: Are the solid particles more compressible or less compressible?
9. S18: Liquids little more and gas molecules the most.

10. T: Are the solids less compressible?
11. S18: [Silent]

The teacher encouraged the class to explain how they could improve Group 8's animation. Only Group 8 commented on their animation, suggesting how they could make it more ideal. Their comments were more about technical matters than their conceptions, per se. This emphasis on technical features was similar to Group 3's response to the discussion of their animation in the Class 11-B. Specifically, S18 commented on the physical properties (at the macro level) of the objects, such as applying heat or boiling, rather than any particular features of the states of matter, such as the motion of the particles or the micro features of a change of state. Consequently, the teacher asked the class about the motion of particles. S24 tried to respond to the teacher's question but S18 responded before S24 could. S18 explained that the gas particles could move past one another easily but that liquid particles move little. The teacher did not make any comment to S18 but invited S24 to express his views about this animation. S24 explained that the drawing of particles should show some motion as the water changes state, but did not mention the movement of solid particles.

12. T: I think, their animation could be improved. What would make this animation a better animation?
13. S18: We did not have a mouse that is why it is like this.
14. T: What did you want to do but you couldn't do?
15. S11: We could have made them boiled.
16. S18: The fires could move.
17. T: Would you give any motion to particles?
18. S18: My teacher, solids couldn't have motion, the gas particles could include motion. Liquids might have little movement.
19. T: What were you saying S24?
20. S24: I was saying that they drew well, but there should be motion on the particles.
21. T: Which part or parts should include motion?
22. S24: For example, from liquid to gas, the particles should include motion and they could show some steam. It would be a better animation.

In Group 8's discussion, no student commented on the different shapes and sizes of particles in each state (see Figure 4.4.15). In contrast to Class 11-B, Class 11-A seemed less critical in their analysis of their classmates' animations, and the discussions were shorter. It is unclear if this was due to a disposition to not critiquing classmates or a consequence of them being less insightful about the relationship between the animation and the underlying concepts. The teacher emphasised that the structure of molecules did not change during a physical change of state (line 23). The teacher also highlighted S18's view about the size of particles because S18 thought that particles get smaller as water changes from a solid to a gas. After the teacher's comment, discussion ended when the class asked no further questions and made no more recommendations about Group 8's animation.

23. T: Any, also, the particles changed their shape while they were turning to a gas phase? Is it possible?
24. Class: [Silent]
25. T: S18 said that molecules were getting smaller while they were turning to gas phase. Is there anyone who wants to comment about this?
26. Class: [Silent]

Group 8's interview took place after the follow-up discussion class, but only S18 was interviewed because S11 had to leave class before the interview. The following section includes the parts of the interview relevant to the follow-up discussion lesson.

Group 8's interview after follow-up discussion class

S18 explained his ideas about the size of particles changing after the follow-up discussion class. He thought that the particles were getting smaller as water was changing from solid to gas. Moreover, even though the teacher emphasised the compressibility of molecules in the class discussion by asking him questions about the compression of a solid and its particles, he made no mention of the property of compressibility as it applied to the different states of matter. Nor did he mention the arrangement of particles in the liquid state, even though Group 8 showed relatively large spaces between the particles in the liquid state (Figure 4.4.15). S18 did not mention this. After the follow-up discussion class, he had become aware that the spaces they had shown between particles had been excessive. Group 8 was the only group that did not claim that they had learned something about the relative spaces between particles in the liquid states. The relevant extract from the interview is shown below.

R: (Through the sequence of events) What did you learn?

S18: When we started, I thought that solid molecules were becoming smaller (when heated) but this is wrong. They don't change they are same. I learned this. And we should be more careful while drawing. For example, in solid liquid and gas size isn't important and we didn't show the same amount.

R: Which size?

S18: Particles should be the same not big or small.

R: Ok. You said this is solid and liquid and this is steam

S18: Yes

R: When it is boiled and turned to steam, are they still in this beaker?

S18: The level of solid should be half, but we didn't think this before we created the animation. It came to our minds later on.

R: Some molecules evaporated and left the beaker, but it didn't come to your mind while drawing?

R: Was the whole process useful?

S18: Yes it was useful. I will use this animation program from now on.

Group 11

Group 11's (S20 and S25) animation was shown on the students' laptop instead of the board. They could not transfer it to the board because they had technical problems. Even though they could use the 'save button' properly in the software program, it was looking more like a fixed image than an animation. When transferred to the board, it was an empty page. The whole class came close to S20 and S25's desk to see the animation. The part of the discussion related with this difficulty is shown below.

1. T: Who is left?
2. S24: My teacher, mine is very good, but I had some problems in transition parts, I got stressed.
3. S20 and S25: (not opened)
4. Class: Laugh (because the screen is empty)
5. S25: We told that it is not opening but we saved it.
6. T: Ok I will open S24's then I will try again to open yours.
7. S21: They decreased the time frame. Actually it is opening but very fast so it is looking like it's empty. It is just appearing and then going blank.
8. T: Ok, open from your laptop. Can everyone see it? My friends, can everyone watch 20's animation?

9. S24: I can’t see. OK. I can see now.

After asking S20 to explain the animation, the teacher was not satisfied with his comments about the melting of a solid. The teacher recognised that S20’s explanation (line 14) was unlikely and tried to get a clearer idea by asking a question from the perspective of the force of attraction between solid particles. S20 said that solid molecules had more free spaces between particles than liquid molecules. According to S20, this meant the solid particles had a stronger attraction force than liquid particles.

10. T: Now explain to us, what did you create, S20?
11. S20: We drew solid, liquid and gas. W couldn’t add heat but I will tell that, like, we had given the heat. The molecules did not melt because they are solid in here. And liquid in here.
12. T: One minute, I did not understand, because of solid?
13. S20: Yes, they did not melt because they are solid. There are molecules between them so we heated but we couldn’t show the heat in the animation so you can’t understand what is it in here. The evaporation started in liquid because of heat.
14. T: There is more attraction force between molecules in liquid state than solid state.
15. S20: Yes
16. T: Because there are more spaces between particles in solid state?
17. S20: Yes my teacher.

After hearing S20’s views about the states of matter, the teacher explained S20’s idea to whole class so as to engage the class in discussion about arrangement of particles (line 19). The class responded by indicating that this idea was not right, but they did not comment further. The teacher then elaborated on the correct arrangement of solid particles (line 24).

18. Yes, S20 is telling us that solid particles have more spaces between particles than the liquid state. Therefore, he put more spaces in the solid state and he drew the liquid particles more closely to each other.
19. T: He is on the right track?
20. Class: No Wrong.
21. T: Yes. Why?
22. Class: [Silent]

23. T: Because there are ignorable spaces between solid particles. But S20's thought is crucial. S20 thought that there are more spaces between solid particles. And when it goes to gas?

After this explanation from the teacher, S13 asked about the arrangement of gas particles. He claimed that there should be more space between the gas particles. Then S20 told S13 why he had drawn smaller spaces (line 26).

24. S13: There should be more spaces between gas particles but they
25. S20: No, no, I drew it like this to show it clearly.

The teacher continued to encourage the class to explain Group 11's animations. S18 said directly that the idea was wrong. S21, however, explained that their ideas are totally different from other animations because, in the gas state, they created a mixture of solid and liquid. Group 11 thought there were still solid and liquid particles in the gas state. However, the teacher stopped the discussion after S21's comment for reasons that are unclear. It might be that the teacher found the idea wrong and did not want this view to remain uncorrected.

26. T: Ok. Do you want to make any comments for S20's animation?
27. S18: His thought is good but if they give heat…
28. T: We skipped it. What else?
29. S18: I think his thinking is wrong.
30. T: Is the thinking wrong? But as a visual representation…(S21 interrupted the teacher)
31. S21: I saw that they drew the mixture of solid and liquid in the gas phase. The gas phase includes both solid and liquid particles. I think it is good and logical.
32. T: Ok, Thank you to S20.

In the interview with Group 11 after the follow-up class, it became clear that they recognised their misconceptions about the arrangement of particles. The next section shows the relevant parts of this interview.

Group 11's interview after follow-up discussion class

Both S20 and S25 expressed a view about the benefit of expert animations that was different from that of others. They claimed that they learned more when they critiqued their classmates' animations and when their classmates critiqued their own animations rather than watching expert animations. They found the follow-up class helpful for their learning. They were satisfied that they had learned the right arrangement of particles for solid particles.

The teacher also mentioned this group in the researcher interview. She explained that when S20 watched the expert animation, he got upset. He was feeling regretful about the quality of his animation. After he saw the animations of his classmates and expert animations, he was aware that he had changed his. Therefore, his willingness to participate in an interview with the researcher was high. He wanted to show someone how well he now understood states of matter. When the researcher asked the teacher why the students were keen to volunteer to be interviewed she explained, [It's] 'because students are happy when they learn'. The relevant extract from the interview is shown below.

R: What did you learn in the whole process? Or did you learn anything?
S25: We learned that there are no spaces between solids
R: In which part of the lesson did you learn it?
S25: While we were making comments to our friends' animations?
S20: While making comments
S25: And when we saw their drawings
S20: And when they made comments on our product. Then we learned.

In the researcher's interview with the teacher, she explained that watching classmates' animations and critiquing each other's ideas was the best part of the process. She claimed that students found mistakes in their classmates' animations. When they found mistakes in other animations, they compared them with their own animations and corrected their own mistakes. They started to look with more critical eyes at their own animations. They asked: How they might improve their animations? Where did they make a mistake? And what should they add? Each group's animation was different from others. They criticised each other. They improved their own animations. She said, 'They got the idea of critical thinking.'

4.4.3. Expert animations (Phase 3)

Animations created by experts using K-sketch (Figure 4.4.1) and other software programs (Figure 4.4.2) were shown to the class, and the students discussed the features in those animations related to changes of state. The students had the opportunity to think more about the movement solid, liquid and gas particles and they explained the consistent and inconsistent parts of their animations by comparing them with the expert animations. During this period of the follow-up discussion class, students mentioned and seemed to confirm the following:

1. The solid particles vibrate and have motion.
2. There is no space between liquid particles and they flow easily.
3. Gas particles have more energy, so they are far from each other.

1. The solid particles vibrate and have motion.

The students were invited to explain their thoughts before and after they watched the expert animations and to critique the expert animations. The students from Group 1 (S7), Group 2 (S1), Group 5 (S16, S17) and Group 8 (S18) talked about the motion of particles and the vibration of solid molecules. The teacher tried to understand whether or not the students' thinking had changed after watching the expert animations. She asked them what they would draw now if they had a chance to do their animation again. They explained that prior to watching expert animations they were not aware that solid particles could vibrate. In other words, they had thought that solid particles are static not dynamic. S7 and S1 said they would show motion of the particles if they were to draw the animation again. S7 would show vibration next time and the teacher supported her by mentioning motion (line 3). When the teacher asked the same question to Group 2 (line 4), they said that they would draw their animation better; they too would show the motion of the particles (line 7). The teacher referred to the solid particles after S1 mentioned the regularity in the arrangement of the particles. The solid particles had been shown in a regular shape and volume in the expert animations (see Figure 4.4.2). The relevant extract is shown below.

1. T: We watched all animations, your friends, your animation, and expert animations; if we draw it again what do you draw?
2. S7: This time I'd show vibrations.
3. T: You are saying that I definitely show particles with motion.
4. T: What you do girls?
5. S1 and S8: Better
6. T: How?
7. S1: We can make the particles regular, give motion to the particles.

The teacher asked the students for their ideas after they watched the expert animation that represented solid, liquid and gas particles at the macroscopic level (Figure 4.4.2).

S17 thought this animation was similar to their own animation but more professional than theirs because experts showed the motion to the particles. S17 (Group 5) said that the solid particles in their animation did show motion. She compared her group's animation with the expert animation and noticed part was inconsistent with the expert animation. The relevant extract from the discussion is shown below.

1. T: Yes, It is the solid, liquid and gas phases of matters. How is it represented? What do you think about this animation? Who wants to talk about it? Yes S17?
2. S17: They mentioned the spaces between particles.
3. T: What about in your drawing?
4. S17: It is close to my drawing, but this one is more professional.
5. T: Where is its professional? What did you like in it?
6. S17: The motion.
7. T: The motion that they gave to particles?
8. S16: Yes, we did not give any motion to the solids.
9. T: Yes, in your animation the solid particles were not moving.

The teacher tried to progress the discussion. S18 explained that after watching the expert animation he realised that solid particles vibrate and there is no space between particles. The teacher also supported his idea and explained the microscopic view of solids to the class. She explained that vibration is shown clearly in the movement of solid particles.

10. T: Yes, What else? Yes S18?
11. S18: In the solid state, the spaces between particles are ignorable, in the liquid phase more and the gas phase more than liquids. But in this animation solid particles vibrate.
12. T: Yes, we see the vibration clearly, don't we? The solid particles are continuously moving with vibration.

After the class had watched the expert animation, Group 5 thought their animation was better than the expert animation (Figure 4.4.12). S17 explained that their animation would be better if they could show the solid particles vibrate. She explained that they did not show the motion in solid phase. The teacher supported S17 and explained that while they thought the solid particles were static the expert animation showed them moving. The relevant extract is shown in below.

1. S17: I think ours was better.

2. T: You think that yours was better?
3. S17: The only difference from our animation is the movement of particles. If we could do this, it could be better. In addition, we did not show the vibration of particles.
4. T: Yes, we had known that the solid particles were held to each other and cannot move. But we see that the solid particles are also moving.

The teacher asked what the students would do if they could draw their animation again? Would it be the same? S17 mentioned again that they would resolve the identified inadequate part, namely the lack of vibration, and it would be better than their previous animation.

5. S17: We add something to our animation according to what we watched or what we see. It would be a better animation.
6. T: It would be better than the previous one. OK. Then what kind of additions to your animation?
7. S17: I already told our deficient parts. Firstly and definitely, I'd vibrate the particles.

2. There is no space between liquid particles, they flow easily.

Students from Group 3 (S6, S9) and Group 5 (S16, S17) said that after watching the expert animations they had learned that there were no spaces between liquid particles. As mentioned in the previous section, 10 of the 11 groups mentioned that they had learned a correct arrangement of liquid particles. The groups had drawn spaces between liquid particles in their animations. They then changed their view stating that there is no space between liquid particles.

Firstly, Group 3 did not believe there were no spaces between liquid particles. Neither S6 nor S9 were sure about this, and S9 asked the teacher, 'Is there really no space?' S6 also asked about the movement of liquid particles (line 4). After the teacher explained the scientifically correct arrangement of liquid particles (line 5), S9 said that the things they had learned before were not right, 'Everything was a lie.' The teacher tried to explain more about the liquid phases of matter but S6 interrupted the teacher indicating that if she had known that there was no space between particles this would have in some way helped her to understand the flow of liquids. They had learnt a correct view about spacing between particles but were making an odd connection between this idea and that of flow. The teacher continued to explain the compressibility of solids and liquids because compressibility had been discussed in the class using Group 8’s animations. The relevant part of this discussion is shown below.

1. S9: But I was not thinking like this for liquid.
2. T: How were you thinking for the liquid phase?
3. S9: But in here there is no space between particles for liquid? Is it no space?
4. S6: Hmm, just vibration?
5. T: Yes. They don't have any spaces between particles.
6. S9: It means everything was a lie. There is no space.
7. T: They flow easily and they can slide past one another.
8. S6: I, hmm, of course if no space then it flows.
9. T: That is why solids and liquids cannot be easily compressed, gas particles are compressible.

Group 5 also mentioned the liquid particles. This group was satisfied with their own animations, but after they had watched the expert animation they realised that the arrangement of liquid particles was different from theirs. The teacher said that they had known that there were spaces between liquid particles.

1. S17: We learned that there is not any space between liquid particles.
2. T: Yes we had known that before. Gas particles have more energy so they are far from each other.

S28, who was absent during the creation of the animations, and other students from Group 3 (S9), Group 5 (S17, S18), and Group 10 (S12) talked about gas particles after they watched the expert animations. S9 said, ‘In the gas phase, some particles go away from the beaker.’ He did not mention the arrangements of particles. He just emphasised loss in boiling and vaporisation by saying, ‘Go away.’

The teacher asked the class about the movement of gas particles. The class was aware of the space between gas particles. The teacher forwarded the discussion by asking about the spaces between gas particles (line 3) and S28 responded that they seemed ‘severed from each other’. The teacher supported his idea and explained that the particles in the gas phase have the highest energy and their movement is fast.

1. T: What do you think about gas particles? Why are they moving faster?
2. Class: They have more space between

3. T: They have more spaces between particles. What do these more spaces show?
4. S28: They are like severed from each other
5. T: Yes they are separated from each other and they have high energy so they move faster.

The class then watched another expert animation. While the animation was playing, the teacher asked about the movement of particles as temperature increased. S17 realised that they were going faster and S28 said that they were turning into the gas phase. The teacher progressed the discussion and S12 mentioned the enlarged spaces between the particles. S28 repeated S12's comment and explained that the spaces increased between particles and they had more energy.

1. T: Let's watch another one. It is cold now. What is happening when we add heat to it? Look at the movement of particles.
2. S17: Speeding up.
3. S28: They are turning to the gas phase.
4. T: After? The particles start to move.
5. S12: The spaces between particles are increasing.
6. S28: The spaces between particles are increasing. Then they are turning to the gas phase. They gain more energy.

The teacher asked the students about the differences they saw between their animations and the expert animation. S18 said that his classmates did not show the molecules vibrating in the solid state and they had created their animation without any motion in all states whereas the expert animation did. The teacher explained that the particles had motion and that they are not confined to the beaker. She also explained that when the temperature decreased, the movement of molecules also decreased.

7. T: Yes, the energy and speed of molecules increased. What did you show while the matter was turning from the solid state to the gas state?
8. S18: We did not show the vibration in the particles like this we just heated it up from the bottom. We showed static.
9. T: Individual particles are attracted to the above, right?
10. S18: Yes.
11. T: The liquid particles are attracted and now we can see that while the particles are going outside the beaker they also have movement. To the opposite direction, to the cold water, what is happening? The movement is slowing down.

In the researcher's interview with the teacher, the teacher explained that initially, students liked their own animations and they were happy with them. When they watched the expert animations, however, they considered that they had many deficiencies in their concepts and they realised that they could improve their animations. She also said, 'Multiple representations developed their conceptual understanding.' She also added that they started to think differently and more broadly after seeing the expert animations. She said, 'We, as teachers, are not teaching them critical thinking. They don't get the chance for their self-reflection. In this process, they got a chance to critique by themselves by watching expert animations. They started to think deeply about the concept.'

In addition, she explained that mostly teachers show expert animations in their classes because it takes too long for students to create their own animations. Nevertheless, she wants to use the process adopted in the intervention in her other classes. She wants to teach all her students how to create animations and she wants to test the effectiveness of creating animations in other classes.

4.4.4. Evaluation of the teaching learning process (Phase 4)

At the end of the follow-up discussion class, Phase 4, the students critiqued the teaching and learning process from the beginning to the end. They also evaluated the third phase of the intervention, Phase 3: the discussion of students and expert animations. The extract related to S6, S7, S9, S18 and S21 talking about the follow-up discussion lesson is reported in this section. First, the teacher asked a question about the follow-up discussion class, in an attempt to understand how it had helped the learning in classes 11-A and 11-B. The students were satisfied that they had corrected their mistakes about the arrangement of particles.

In Class 11-B, S7 explained her opinions about the discussions. She claimed that without those discussions, they could not have learned the right concepts or developed an appropriate understanding of the concept. Without the follow-up discussion lesson, they could not have confronted their misconceptions. S9 also agreed with S7 and stated that he learned his most accurate conception in the follow-up discussions. S6 also expressed satisfaction with the whole teaching process and commented that the education system should use it. S7 then summarised the whole process as 'Imagine, Create, and Discuss.' She implied that they formed new images in their minds, and then they used their imagination to create the animation. After creating through imagination, they discussed what they imagined. She also said that the whole process was enjoyable. The relevant extract is shown in below.

1. T: What about if we don’t have this follow up discussion lesson?
2. S7: Maybe misconceptions would have stayed in our minds, and they cannot be corrected.
3. S9: We learned the most accurate one.
4. (Teacher mentions multiple representations)
5. S6: I think the education system should be like this…
6. S7: I really enjoyed. First: imagine then create then discuss.

In Class 11-A, S18 and S21 talked about the follow-up discussion class. S18 explained that he was not aware of the accurate arrangement of gas particles prior to the follow-up discussion class. He claimed that it helped him to correct mistakes about the changes of state. S21 realised that they all have multiple thoughts about the same concept. She claimed that they also had a chance to compare their own thinking with their classmates. The relevant extract is shown below.

1. T: If you hadn’t watched the expert animations and you hadn’t evaluated your classmates’ animations, what would you think about the teaching process? What would happen if the teaching had been finished after you had drawn your animation? What was the contribution of follow-up discussion class to your learning?
2. S18: There were some mistakes or misconceptions in some group’s animations. For example, if we didn’t discuss the movement of gas particles that were including easier flow, we couldn’t get appropriate understanding of the concept. Our mistakes could not be corrected. I think it was good.
3. S21: Yes, we critiqued, and we saw the differences between our animation and the other group ones. We realised that we were all thinking differently, our thoughts are different from each other.
4. T: In the animation, we saw the different points of view in … discussions.
5. S18: We corrected our mistakes.

In the researcher’s interview with the teacher, the teacher evaluated the whole animation process in a similar way to the students. The researcher asked her, ‘Is creating an animation necessary for understanding the states of matter concept?’ The teacher said, ‘If you had asked this question before the process, my answer would have been No … It is a very basic concept, but students have many misconceptions about it. Students learned it wrongly and I did not realise their misconception until Year 11.’

She explained that the students had learned the nature of solid, liquid and gas particles from Year 6 but they had also developed many misconceptions that she had not been aware of. She was worried that the students may continue with these misconceptions during their future education. She also explained that in this learning strategy students questioned their claims, and she can understand the students’ thinking when they create animations. She continued, ‘The explanations of matched and mismatched properties also helped the students to see their mistakes and be aware of their misunderstandings in this process. They corrected the misconceptions of the students, [who] got a chance to think again about the concept as they engaged in self-evaluation.’ She said, ‘Thanks to this learning strategy, students were helped to become aware of their misconceptions.’

In her evaluation, the teacher said the whole process would not have been effective if the students had created their animations without discussing and watching the animations of the other students and the experts. She also noted, ‘When students learned the concept well, they critiqued expert animations. When they really reached the conceptual understanding, they would have critical thinking about concepts.’ She said that when students watched an expert animation, ‘their thinking process started again’ as they asked how they can use the features of the expert animations in their own animations. The expert animation helped them to learn the details of the concept being studied.

In addition, the teacher said it was interesting that ‘animations have not the same effects on each student’. She claimed that animations affected each student differently. She gave the example of how it was not until she saw S4 create his animation that she realised he had an incorrect perspective, even though he is usually good at chemistry. By contrast, she was pleasantly surprised by the animations of S20 and S22, who are not good in chemistry. S22’s animation was conceptually more accurate than her other classmates, and S20 improved his thinking about this concept more than all other students did.

Finally she added, ‘I realised that there is a big difference in the ways students’ accept [ideas] when they see animations. I will use animations the rest of my teaching life. I think we can use animations for 80 % of chemical concepts. I will definitely use them.’

4.5. Conclusion

This chapter has presented data from student-generated animations along with analyses and discussions conducted during a six-week period. The chapter began with a statistical analysis of the ESSA questionnaire. Statistically significant differences were found between the pre- and post-test results for the states of matter concept. Next, the phases of interventions were highlighted, with the data providing significant evidence that when students created their animations with partner interactions and teacher support, they enhance their awareness about their own thinking. Discussions and analysis of those animations in the learning environment improved their science understanding.

The data also indicates that the representational construction approach (Tytler et al. 2013c) and analogical thinking, as discussed in Chapter 2, formed a powerful framework for the effective use of student analogies with discussions and teacher support in conceptual science understanding. The next chapter, Chapter 5, presents the discussions of the findings from the data and conclusions from both theoretical and practical consideration

Chapter 5: Student-Generated Animations and Students' Learning in Chemistry

5.1. Introduction

Representations are often used to help students to develop their understanding of science concepts (Tytler et al. 2013), but successful learning where students create their own animations has rarely been reported (Chang & Quintana 2006; Hoban et al. 2009; Hoban & Nielsen 2010). What is distinctive about this research is the use of an intervention to investigate how student-generated animations, together with critical analysis and discussion, influenced students' learning of chemistry. The use of software programs for supporting student-generated animations encouraged students to represent their existing knowledge using animations and helped both the students and their teacher to identify where students had sound understandings, deficiencies and misconceptions. The following four research questions guided this study of how student-generated animations influenced students' learning of chemistry:

1. In what ways do student-generated animations influence students' conceptual learning in chemistry?
2. How do interactions among students influence learning when they are creating animations?
3. How do interactions between teachers and students influence learning in the animation creation process?
4. How do analysis and discussion of the animations contribute to students' learning?

As outlined in Chapter 2, the study draws on three theoretical approaches: social constructivism (Ernest 1998; Gredler 1997; Maxim 2014; Prawat & Floden 1994; Vygotsky 1978), the Representation Construction Approach (RCA) (Tytler et al. 2013c), and learning through analogies (Ainsworth 1999; Aubusson et al. 2006; Aubusson et al. 2009; Barlex & Carre 1985; Carolan et al. 2001; Harrison & Treagust 2006; Prain & Waldrip 2008; Saul 2004).

Social constructivism emphasises the interactions in groups during an active learning process. The conjecture framing this study is that student collaboration in creating their animations would promote interactions with each other and their teacher to enhance students' understanding of science concepts.

The two principles of the RCA (Tytler et al. 2013) suited the purpose and context of the research (see Section 2.2.2). First, the students actively created their animations as representations that helped to explain and enhance their understanding of the chemical phenomena; and second, throughout this process and subsequent discussions, students were supported by their school partners and their teacher as they developed their conceptual understanding. The inclusion in this study of follow-up discussion classes also stems from the RCA and the principles of teaching with analogies. These discussions allowed learners to compare and synthesise their own and the experts' animations

The use of analogies is consistent with the RCA. Analogies encourage learning by allowing for the identification of similarities, consistencies and inconsistencies between concrete (analog) and abstract (target) concepts (Aubusson et al. 2009). In this case, the animations were analogs of the target chemistry phenomena (see Section 2.2.3)

The results of this study suggest that the students developed their understanding of chemical concepts from participating in this process. In particular, pre- and post-test results showed that they developed an expanded knowledge of chemistry and states of matter when they used the software animation program to construct their own representations.

This chapter synthesises the findings from the wide range of data collected in this study. This is contextualised in relation to the four research questions shown above. The implications of these findings and the limitations of the research will then be considered along with recommendations for further research.

5.2. Findings

This section draws together the research findings of this study. Following a brief outline of the pre- and post-test results, the findings will be summarised in the context of the four research questions introduced in Chapter 1 and repeated in Section 5.1.

5.2.1. Pre- and post-test results

Evidence of student learning was sought through pre- and post-tests. After the pre-tests, the concepts underpinning the four research questions were taught through the animation creation process. The students drew the animations for the states of matters showing particles, watched their classmates' and experts' animations and then discussed these animations. They matched and mismatched attributes from those of the expert animations with their own animations. Within groups, they then participated in stimulated recall interviews before taking the post-tests.

Students had statistically significant higher scores on post-test scores in comparison to pre-tests results (see Table 4.2.2). This result is consistent with previous studies where ICT simulations have been used in chemistry teaching. Studies consistently show that students' performance increases in chemistry tests when teachers use computer-based science simulations (Chang & Quintana 2006; Hubscher-Younger & Narayanan 2007; Udo & Etiubon 2011). Williamson and Abraham's (1995) study based on pre- and post-test results also supports the case that usage of animations contributes to an increase in students' scores. Students' 3-D structures also improve with web-based materials based on pre- and post-test results (Dori, Barak & Adir 2003).

This study shows that students' understanding improved with use of student-generated animations combined with discussion and analysis of the concepts underpinning these animations.

Research findings in relation to the research questionsResearch question 1

In what ways do student-generated animations influence conceptual learning?

As mentioned in Chapter 4, all students were actively engaged during the animation creation process in which the intervention was applied. They worked with their partners or within groups and created a chemistry animation using the K-sketch animation program. The students said they had created better animations in small groups than they would have as individuals, with the small group discussions helping them to think through ideas underpinning their concepts. While creating their animations, students had friendly discussions, were smiling and sometimes singing. When they disagreed with each other, most tried to negotiate and eventually found common explanations and reasons on which to base agreements.

The teacher also reported that before they started to create their own animations there was useful discussion among students, which encouraged them to think about the concepts. The teacher became aware of students' misconceptions and otherwise hidden understandings while they were creating their animations. This negotiation of meaning is consistent with a socio-cultural perspective of learning.

After creating their animations, the groups showed their animations to other classmates by displaying them on the board. Most students exhibited confidence while they were explaining their animation to the class and answering questions. They tried to explain what they had been thinking while they were creating their animations. Comments from their classmates and teacher helped them to become aware of their own and others' misconceptions. Video recordings show most students enjoying their classmates' animations and the discussions that followed. They were smiling and making comments such as 'excellent', 'different', and 'perfect'. They also started to look at animations with a critical eye. They learned how to improve the ways in which their animations represented their concepts of states of matter.

After observing and commenting on their classmates' animations, the students watched the experts' animations on the states of matter. They indicated that watching the experts' animations was an indispensable part of learning through the animation creation process. Many expressed surprise that they still lacked understanding of these concepts despite having studied them many times at school. For some, the experts' animations allowed them to recognise deficiencies depicted in their own animations and their misconceptions about the arrangement of particles in liquids. Many had represented their ideas accurately, only to realise these ideas were wrong. Others became able to distinguish between ideas that were conceptually correct but representationally inaccurate due to difficulties in drawing them.

While a student's individual creating or drawing of chemistry images has been shown to help improve their visualisation and education at the micro level (Eilam & Poyas 2010), this research suggests that the use of student-generated representations in combination with analysis of animations and discussions supports the learning of fundamental basic chemistry concepts such as states of matter.

When novices use relatively unfamiliar software, the animations they generate will never be able to represent accurately their visualisations. However, errors in an animation or representation do not necessarily mean its creator has the particular misconceptions suggested by the animation. The animation is needed as a tool for the imagination. Without engaging in the process of drawing the animation to represent their views, students tend to be concerned about the risk of being lost in their own ideas and being relatively unproductive as learners. Their attempts to imagine what happens as matter changes states makes them more receptive to learning from others, particularly the experts' animations. This is also related to the critical initial step in constructivist learning where learners articulate their ideas (Maxim 2013). Continuing dialogue that includes public and open acceptance appears important for exploring and developing ideas. The follow-up discussions where students compared their own animations with those of their classmates and those of experts were therefore important elements of the learning process.

To conclude, all the students said they preferred using the animation software and found it more enjoyable and encouraging than the traditional learning methods they had experienced. For example, in the evaluation process, one student claimed that the whole process was better than the current 'education system' and she summarised the whole process as 'imagine, create and discuss'. Her classmates agreed, saying: 'exactly', 'same thinking', the 'education system should be changed'. In addition, the teacher also claimed that there was a big difference in the students' conceptual understanding before and after the creating animations intervention. She therefore preferred using student-generated animations rather than expert animations alone because while students are drawing, they start to think and imagine, and their cognitive engagement increases. In addition, she claimed that after students had drawn their own animations, they gave more attention to the expert animations as they sought the similarities and differences between their animations and those of the 'expert' animators.

These experiences are consistent with those reported by other researchers. Chang and Quintana (2006), for example, concluded that student-generated animations have an encouraging effect on the learning environment of middle-school students. Barak, Ashkar and Dori (2011) also report that students who studied science with animated movies had more motivation to learn and enjoy science than students who studied with traditional methods.

Research question 2

How do interactions among students influence learning when they are creating animations?

Students worked in groups while they were creating their animations. Student interviews and videotapes of their interactions show how they interacted with partners to clarify chemical concepts and gain advice, information and confirmation. Their interactions were divided into the following five categories: seeking understanding of the partner's claim; giving instructions to the partner; adding new information; advising and convincing; technical discussion (see Section 4.3.1). Such interactions appeared effective when pairs of student partners engaged in the discussions and shared ideas about a concept. According to Jonassen, Peck and Wilson (1999a), collaboration among students helps their personal growth and contributes to high levels of student satisfaction; improves both their relationships with others and their communication skills; increases motivation, knowledge and respect of each other's opinions; and helps them to learn to listen respectively. This is consistent with Stieff, Bateman & Uttal's (2005) assertion that students using a visualisation tool in group work share their ideas and learn each other's alternative views about an idea or concept. It is also consistent with social constructivist view on learning: students interacting in a group construct knowledge for each other and create a small culture to solve a given task collaboratively (Richard & Audrey 2004). In this study, each partner asked questions and requested advice about unclear concepts (see Example 4, Section 4.3.1). The learning and knowledge were thus constructed through social interactions in groups.

These results are consistent with Vygotsky's (1981) theory of learning through social interactions and the research of Barak, Ashkar and Dori (2011), who, as mentioned earlier, found that students who studied science using animated movies increased their understanding through subsequent group discussions. They shared their ideas and socially negotiated meaning as they realised that there are various ways, other than their own, to solve problems or reach a conclusion.

The social constructivist perspective on student learning also highlights the critical role of interactions among peers for their cognitive development (Ernest 1998; Gredler 1997; Prawat & Floden 1994). This accords with the students' and the teacher's claims and is consistent with Jonassen, Peck and Wilson's (1999b) assertion that when students work together and discuss in groups rather than doing individual work, they develop their cognitive strategies and knowledge about what they are doing, along with their understanding about why they are doing it.

However, in this study interactions were not so effective when a partner gave directions instead of explanations, or when a dominant partner was happy to be involved in the group's work but a passive partner was silent or disengaged. Except for two students who had passive partners, all acknowledged that the group work would have been less enjoyable without their partners' contributions.

Research question 3

How do interactions between teachers and students influence learning in the animation creation process?

The teacher played an active role in supporting an atmosphere in which the creating of animations was part of an effective learning environment. While the students were creating the animations, she encouraged them to be confident in exposing themselves to the risk of being wrong and to show their thinking freely. She explained that there would be nothing wrong in their animations; there would be only different ways of expressing their ideas. She also explained that they could ask any question if they were unclear; she would be their guide. Even though many students were confident as they explained their animations to their classmates, the groups that demonstrated less conceptual understanding in their pre-tests showed less certainty when interpreting their ideas for the class discussion. In these cases, the teacher asked these less confident students (those who talked less about their animations) structured guiding questions in order to to promote their understanding. These guiding questions helped the students to both understand and explain the correct science related to the concepts. Barlex and Carr (1985) argue that for teachers to work consistently within Vygotsky's (1962) zone of proximal development (ZPD), it is essential that they help students to give expression to their own ideas in the learning process. Students often need help in their learning experiences with visual materials so that they can become aware of what they should attend to or ignore (Barlex & Carre 1985).

The teacher observed the students while they were using the K-Sketch animation program and discussing their animations with their partners, and she reminded them of what they were attempting if they deviated from representing their conceptual understanding. She asked questions and summarised their drawings to help them improve and organise their interpretation of the concepts. Consistently with the principles of Vygotsky's ZPD, her scaffolding of the groups as they were animating helped elicit the students' current views of science and correct their misconceptions. In addition, asking them to make reasoned claims about the concepts is consistent with reports indicating that verbalising claims when drawing helps students to synthesise concepts (Tytler et.al. 2013c). Aubusson and Fogwill (2006) also argue that it is important for a teacher to cooperate with students as they together generate their analogies (animations in this research) not only by telling students what to present but also by questioning and exploring their views. In this study students were required to explain and elaborate their ideas about science phenomena, the reasoning underpinning these views and the ways in which these ideas are being illustrated in their animations.

Of the 11 groups of students interviewed, four groups reported that the teacher's support was useful because she had helped them to improve their animations by bringing their attention to concepts they might never have thought about, such as 'adding motion' and 'vibration of particles'. Two groups said they were neutral about the teacher's support because when she tried to guide them she only watched their animating and said nothing. Four groups mentioned that the teacher's support during the partner discussions was not useful and did not affect their work. While she had asked questions about their work while they were doing it, they decided her support was unnecessary and they attempted to create their animations without her guidance. The perceptions of this minority of students is inconsistent with the view of the researcher observer, who noted that changes to the animations often occurred after interactions with the teacher and that students became clearer about the expectation that they represent their conceptions in their animation. The minority of students who found the teacher's scaffoldings to be not useful might have expected a direct instruction from their teacher to contribute to their animations. This is evident in the teacher-student dialogues that show that even though the teacher interacted with the groups by simply asking what they were doing in order to help them to think again about the concept, these students were either not aware of this support (see Example 22, Section 4.3.2) or they realised they were doing something wrong and intended to change their animations just after the teacher had analysed their drawings (see Example 24, Section 4.3.2).

Analysis of the teacher-student dialogues suggests the following categorisation of the teacher's scaffolding:

- repeating a student's previous sentence and asking further questions
- reminding students of what they are attempting
- clarifying the student's claim
- summarising student's drawings and eliciting information
- encouraging students

- providing additional direct information
- highlighting significant omissions
- recommending changes to address these
- asking a reason for something or seeking an explanation
- providing misleading comments (see Section 4.3.2).

For the most part, the teacher intervened gently during the student-generated animation process. She gave students the task, encouraged them to collaborate, and as she walked around she asked what they were doing. In the follow-up discussions, she did intervene more assertively when she initiated the discussions and assisted students to map the features of both their own animations and the expert animations, such as the target and base analogs (Aubusson, Treagust & Harrison 2009). She helped students to identify, discuss, explain and map the similarities and differences between students' and expert's animations. With this sort of mediation, the learning was more valuable than if the students had viewed the expert's animation alone. This observation is consistent with claims that the mapping of the match and mismatch of attributes between base analog and target phenomenon during the discussion of analogies (animations in this research) may be more valuable in students' learning than the development of a more accurate base analog per se (Aubusson, Treagust & Harrison 2009). In other words, inadequacies may be advantageous because they become sites of learning during the discussion of analogies (animations). This study thus provides evidence that is consistent with other research regarding expert analogies and perceived inadequacies (Aubusson & Fogwill 2006; Fogwill 2007).

Research question 4

How do analysis and discussion of the animations contribute to students' learning?

In order to answer this question, I will focus on the follow-up discussion lesson, which was the culmination of the learning sequence.

After working in groups to create their animations, the students met in their follow-up class to discuss their ideas about other classmates' animations, either accepting the other student's ideas or challenging them. They talked about how the animations were developed and how the ideas represented by others matched and mismatched their own.

During these critiques of the students' animations, the teacher initiated the conversations, sought explanations of the fundamental concepts that related to change of state and encouraged the students to discuss the ideas presented in the animations. The teacher tried to stimulate their deeper analysis of the animations by asking how they might make the animations ideal. There were multiple ideas about this. However, sometimes when the teacher found ideas to be wrong she stopped the discussions rather than correct the students' conceptions. In other words, she tried to help the students to think about why an animation might be inadequate and how it could be improved.

The format of the follow-up discussions was consistent with the Focus-Action-Reflection (FAR) guideline for teaching with analogies and models (Treagust et al. 1998) (see Section 2.2.3). In the Pre-Lesson Focus stage, the teacher selected and clarified the abstract concept states of matter. Students revealed ideas they already had about this concept by creating animations. During this animation creating process, the teacher discussed with the students and asked questions about their animations to establish evidence of any prior knowledge of the concept.

In the Lesson Action stage, the teacher discussed the students' animations, including mapping attributes of the animation that are like or unlike the target analog. The follow-up discussions about how the students saw the matches and mismatches between their own animations and those of their classmates and the experts appeared to be an essential element of the learning process. The teacher's comments and the students' post-test results show this helped the students to focus on the main concepts to be learned and to minimise the generation of further misconceptions.

In the Post-Lesson Reflection stage, the teacher asked the students to evaluate the whole animation creating and discussion process. Students shared their experiences during the learning process and discussed their ideas with the teacher. The teacher asked questions based on the FAR guide (Treagust, Harrison & Venville 1998), including: What kinds of changes or improvements are needed in future lessons? Which part of the process was more useful? Which was the most powerful part of the process – creating the animations or discussing them?

The students also improved their conceptual understanding by discussing and asking questions about those parts of their classmates' animations that were inconsistent with their own ideas. While they were watching their classmates' animations, they realised that many in the class did not have the same understanding as the group whose animation was being shown and critiqued.

After these discussions of their classmates' animations, the students watched the experts' animations about changes of state. As noted above, studies show that computer-based science simulations related to chemistry concepts help students to develop their conceptual understanding (Chang & Quintana 2006; Hubscher-Younger & Narayanan 2007; Udo & Etiubon 2011). However, the intervention in this research has approached the topic differently, with the students watching the expert animations only after they produced their own animations. They watched the expert animations and critiqued them, highlighting the similarities and differences between the 'expert' animations and their own animations. They distinguished not only the different parts of the animations but also when their ideas about the concepts were unclear or inconsistent with the expert animations. Even though students were initially unsure about how to critique their classmates' animations, they gained confidence during this process and learned how to critique even the expert animations. The videotapes show the surprise of a student who said at this point, 'Oh yes, I got it,' and the happiness of another who commented, 'Chemistry is not as difficult as I was thinking before.'

Students also revealed that it was helpful to see the expert animations after they had critiqued their classmates' animations. Some groups changed their ideas after watching the expert animations even though they had been satisfied with their animations after the classmate discussions. In addition, as indicated earlier, while students were comparing the features of the expert animations that were consistent or inconsistent with the features of their animations, they became aware of deficiencies in their own conceptualisation of states of matter. For example, even though some students claimed they understood the motion of particles on each state, they became aware of the correct arrangement of particles within the liquid phase after watching the expert animations (see Section 4.4.3).

According to the teachers and students, however, watching expert animations alone would not have been as helpful for learning had they not already constructed their own animations. This is broadly consistent with Hoban et al.'s (2013) claim that creating animations improves students' content knowledge of chemistry and students need to think in multiple representations of the same concept in order to reach the final representation. This study indicates that producing and critiquing a variety of student and expert animations contributed to learning and created an opportunity to see multimodal representations. This is consistent with other findings that multiple representations support students to both demonstrate and extend their science learning (Ben-Zvi et. al 1986; Harrison & Treagust 2000; Tytler, Waldrip & Griffiths 2004; Waldrip & Prain 2013).

Of the 11 student groups interviewed, only one group did not mention the follow-up class discussions either positively or negatively. The other groups were satisfied that they had learned about the arrangement and movement of particles through these discussions. They said that prior to the follow-up discussion class, none of them was aware that liquids do not have significant spaces between particles. Showing their animations to the whole class allowed them to explain their thinking and continue to improve their understanding about the states of matter. They reported that they had learned the following three key concepts related to states of matter:

1. Solid particles have vibration and motion.
2. Liquid particles flow above each other, and they do not have spaces between particles.
3. Gas particles have large spaces between particles because of their high energy.

In summary, the students claimed they could not have learned the correct concepts about states of matter without having participated in the discussions that followed the creation of their animations. Without their own student-generated animations, it would have been impossible to imagine or think about the concepts in the same way. The pedagogic value came from the combination of both creating the animations and having the follow-up discussions.

5.3. Implications

This research illustrates how combining the production of student animations with interactive discussions is an effective way of developing students' understanding of chemistry concepts. An implication of this research is that science teaching in general might benefit from the development of multiple ways (creating, discussing, evaluating) of using student-generated animations.

This study shows that when students create and analyse animations they seem more likely to be aware of the dynamic nature and motion of particles in the three states of matter, particularly vibration in solid state. Teachers should consider the integration of animations that include motion and also enable their students to find opportunities to create them. Through such learner-generated animations, students can render their thinking ‘visible’ and help teachers take targeted action that supports students to understand relevant concepts.

Discussions about their own animations allowed students’ ideas to become explicit and created a learning environment in which students not only asked questions and clarified their own ideas but also compared and contrasted their ideas with those of other students. This is aligns with the theory of social constructivism: meaning is created and knowledge constructed during the interactions between students and their teachers.

With regard to group work, while the students were working on the same task (generating science-animations) they integrated their varied ideas and found themselves in an explanatory framework. Group discussions created a learning environment that engaged students in developing their understanding. Therefore, creating an animation with partners is recommended as an instructional intervention to improve the learning of scientific concepts.

5.4. Limitations

The study was originally planned to be conducted in three different colleges in Turkey, but two schools withdrew from the research at short notice. This reduced the sample size and prevented comparisons with varied forms of the intervention. The sample size (N = 28) was therefore limited by the availability of the students in the remaining college and how many there were in the teacher’s classes. Thus, the results drawn from the data cannot be generalised to other learning settings and grade levels or to all teachers. Rather, the reader needs to consider the context of this study and determine the confidence with which its findings might be applicable to guiding practice in other settings (Aubusson 2002).

The research design included using the CamStudio software recording program to record the students’ screen while they created their animations. However, all except two groups of students found that they could not use the program, and it became time consuming to rearrange the program and change its settings during the process. Even the two groups of students who were already familiar with this program found that transferring recorded data to the researcher’s hard disk took two or three hours. This problem led to the data from CamStudio source being unavailable.

Another limitation was that only two student groups had video cameras to record their experiences. The researcher and the teacher recorded the partner discussions with smart phones, but use of video cameras with each student group to show details of conversation and gestures as they animated would have enhanced the collection and quality of the data.

5.5. Further research

During this research, student-generated animations were used as an intervention for learning abstract concepts. Student groups each constructed an animation that showed their collective view of states of matter. Discussions about their own animations were designed to promote students' interactions and to ascertain their understanding about the changing physical phases of matter. After discussions, they watched expert animations and critiqued them. They then evaluated the whole teaching and learning process in the classroom environment. I offer five suggestions for further research in this area.

First, researchers might attempt to replicate this study with a large number of students in order to increase the reliability of the intervention. Because the late withdrawal of two schools from the research reduced the sample size and left only the current research data available, it has not yet been possible to compare variations on the intervention.

Second, implementing distinct parts of the intervention separately, or repeating the study with selected elements of intervention removed, could yield valuable insights into the relative importance of different phases of the intervention. Examples could include an analysis of the expert animations only or of the students' construction of their own animations without taking the experts' animations into account. The intended comparison with a class using student-generated animation alone without follow-up discussion was not possible due to a school's late withdrawal, so this would also be a useful next step.

Third, research with a comparison group of students who draw but not animate would tease out the role of dynamic representations in this group's understanding of science concepts.

Fourth, because this research studied only one concept and this was limited to only three states of matter, it would be productive to investigate other key concepts in fields additional to chemistry. Fields involving dynamic, microscopic and macroscopic process, such as physics, geology and biology, are difficult to visualise. The findings of such investigations should inform the extent to which students may benefit from generating animations in these fields.

Fifth, it would be useful to repeat the process with the same class but with a different concept. The intervention was a time-consuming process, which may be due to its being introduced to a class for the first time. There would be value in researching whether the process could become quicker, with the students needing less of their teacher's scaffolding.

Further investigations such as these will add to our understanding of how to use student-generated animations to promote students' learning in science.

5.6. Conclusion

The multi-faceted nature of this research into student-generated animations demonstrates the intersection of educational theory and practice. It not only adds to the body of knowledge about the value of animations in teaching chemistry but also illustrates how the student-generated animation creation process can positively affect students' learning. The application of RCA and analogical reasoning in student-generated animations supports the case for its pedagogical usefulness.

The study also identified how the interactions of students helped to clarify their understanding and misunderstanding about the chemistry concepts. Student-generated animation, when supported by teacher-led discussion and analysis of animations, appears to be an effective form of science teaching and learning. The scaffolded support from the teacher in the follow-up discussion classes extended students' conceptual understanding and improved their representational mapping skills. Therefore, this research extends the knowledge of using student-generated animations.

Aubusson and Fogwill (2006) have speculated that the errors and imperfections in student-generated analogies create a locus for learning and that relatively poor student generated analogies may be better stimuli for learning than perfected analogies. Poor analogies do not represent a phenomenon with scientific accuracy. The goal, they argued, was not to perfect the analogy but to use it to enable learning. There is ample evidence in this study that adds weight to this speculation. Indeed, it could now move from mere conjecture to a sound assertion.

The inadequacies, inaccuracies and failings in the student-generated animations were used to enable the learning process, whether or not these resulted from a student's imprecise conceptualisations or an inability to render conceptions clearly using the animation software. It is recognised that student's who share their misunderstandings and misrepresentations may promote further misconceptions among others (Osborne & Cosgrove, 1983). Yet the evidence from this study is that the student-generated animations brought both understanding and misunderstanding to the fore. There is almost no evidence that misunderstandings were either appropriated by students or shared by them. Rather, the data suggest that with the application of an appropriate pedagogy, students' thinking is sufficiently robust to not only deal with potentially misleading animations but also to learn from them. When stimulated by students' own animations, the discussion and comparison with expert animations generated understanding.

Because scientific conceptions such as these are much more difficult to illustrate in static drawings, the specific affordance of animation in this intervention is its capacity to represent their dynamic elements. Animations can show the dynamic features of a situation 'directly and explicitly' (Hubscher-Younger & Narayanan 2007, p. 235) and help students to visualise dynamic processes (Dori & Barak 2001; Najjar 1998). Even so, it was challenging for students to show in their animations the molecular movement exactly as they intended, and this sometimes led to imperfections in their representations rather than inaccurate conceptualisations per se.

While this research was being conducted and the thesis written a popular song played repeatedly on the radio. It included the line, 'I love your perfect imperfections.' As educators, a clear message of this thesis is that, for the purposes of learning, we should love the perfect imperfections of student-generated animations because therein lies opportunity for learning.

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Appendices

Appendix 1 Ethics Approval

Thank you for your response to the Committee's comments for your project titled, "The Effects of Student-Oriented Chemistry Animations on Conceptual Learning Processes". Your response satisfactorily addresses the concerns and questions raised by the Committee who agreed that the application now meets the requirements of the NHMRC National Statement on Ethical Conduct In Human Research (2007). I am pleased to inform you that ethics approval is now granted.

Your approval number is UTS HREC REF NO. 2012000391

You should consider this your official letter of approval. If you require a hardcopy please contact the Research Ethics Officer (Research.Ethics@uts.edu.au).

Please note that the ethical conduct of research is an on-going process. The National Statement on Ethical Conduct in Research Involving Humans requires us to obtain a report about the progress of the research, and in particular about any changes to the research which may have ethical implications. This report form must be completed at least annually, and at the end of the project (if it takes more than a year). The Ethics Secretariat will contact you when it is time to complete your first report.

I also refer you to the AVCC guidelines relating to the storage of data, which require that data be kept for a minimum of 5 years after publication of research. However, in NSW, longer retention requirements are required for research on human subjects with potential long-term effects, research with long-term environmental effects, or research considered of national or international significance, importance, or controversy. If the data from this research project falls into one of these categories, contact University Records for advice on long-term retention.

If you have any queries about your ethics approval, or require any amendments to your research in the future, please do not hesitate to contact the Ethics Secretariat at the Research and Innovation Office, on 02 9514 9772.

Yours sincerely,

Professor Marion Haas

Chairperson

UTS Human Research Ethics Committee

C/- Research & Innovation Office

University of Technology, Sydney

Level 14, Tower Building

Broadway NSW 2007

Ph: 02 9514 9772

Fax: 02 9514 1244

Web: http://www.research.uts.edu.au/policies/restricted/ethics.htm

Appendix 2a Student Consent form

UNIVERSITY OF
TECHNOLOGY SYDNEY

(i) CONSENT FORM

THE EFFECTS OF STUDENT-ORIENTED ANIMATIONS ON LEARNING PROCESS 2012000391

I ________________ *(participant's name)* agree to participate in the research project ***THE EFFECTS OF STUDENT-ORIENTED ANIMATIONS ON LEARNING PROCESS 2012000391*** being conducted by Zeynep Polat with phone number , and student number of the University of Technology, Sydney for his/her degree PhD in Faculty of Arts and Social Sciences, Education. Zeynep Polat is the UTS international research scholarship student.

I understand that the purpose of this study is to find out about the impacts of student-oriented animation programs on student learning for the fundamental chemistry concepts.

I understand that I have been asked to participate in this research because I want to explain the effects of student-oriented animations on high school students' learning process and that my participation in this research will involve learning of the animation program, creating the new animation for the chemistry concept as pairs and 15-20 minutes interviews with students. I will treat all students and their answers with respect during interviews. I will also use pseudonyms-fake names-for schools and the students not to reveal the identity of them in research publications, reports or presentations. All digital video-audio recordings and transcriptions will not be accessible to others other than me and my supervisors.

I am aware that I can contact Zeynep Polat or her supervisor(s) Assoc. Prof. Peter Aubusson and Matthew Kearney in Faculty of Arts and Social Sciences, Education if I have any concerns about the research. I also understand that I am free to withdraw my participation from this research project at any time I wish, without consequences, and without giving a reason.

I agree that Zeynep Polat has answered all my questions fully and clearly.

I agree that the research data gathered from this project may be published in a form that does not identify me in any way.

________________________________ ___/___/___

Signature (participant)

________________________________ ___/___/___

Signature (researcher or delegate)

NOTE:

This study has been approved by the University of Technology, Sydney Human Research Ethics Committee. If you have any complaints or reservations about any aspect of your participation in this research which you cannot resolve with the researcher, you may contact the Ethics Committee through the Research Ethics Officer (ph: +61 2 9514 9772 Research.Ethics@uts.edu.au) and quote the UTS HREC reference number. Any complaint you make will be treated in confidence and investigated fully and you will be informed of the outcome.

Appendix 2b Teacher Consent form

(ii) ***CONSENT FORM-Staff***

THE EFFECTS OF STUDENT-ORIENTED ANIMATIONS ON LEARNING PROCESS FOR CHEMISTRY CONCEPTS 2012000391

I ________________ *(participant's name)* agree to participate in the research project "The Effects of Student-oriented Animations on Learning Process for Chemistry Concepts" ***2012000391*** being conducted by Zeynep Polat with phone number [redacted], and student number [redacted] of the University of Technology, Sydney for her PhD degree in Faculty of Arts and Social Sciences, Education. Zeynep Polat is the UTS international research scholarship student.

I understand that the purpose of this study is to find out about the impacts of student-oriented animations on student learning for the fundamental chemistry concepts.

I understand that I have been asked to take part in creating animation program for two class hours and support students when they are creating their animations. When students are creating animation program with their partner, there will be recording program to record every step of their animation. In addition, video and audio recording will take place during creating their animation. In video recording students' face will not be detected. The interview will be audio-recorded, and this recording will be turned into a typed transcript. You don't have to answer a question if you do not want to. The researcher will treat all students and their answers with respect during interviews.

I understand that Zeynep Polat will also use pseudonyms-fake names- for the schools and for me and students not to reveal the identity of us in research publications, reports or presentations. All digital video-audio recordings and transcriptions will not be accessible to others other than Zeynep Polat and her supervisors.

I am aware that I can contact Zeynep Polat or her supervisor(s) Assoc. Prof. Peter Aubusson and Matthew Kearney in Faculty of Arts and Social Sciences, Education if I have any concerns about the research. I also understand that I am free to withdraw my participation from this research project at any time I wish, without consequences, and without giving a reason.

I agree that Zeynep Polat has answered all my questions fully and clearly.

I agree that the research data gathered from this project may be published in a form that does not identify me in any way.

________________________________ ___/___/___

Signature (participant)

________________________________ ___/___/___

Signature (researcher or delegate)

NOTE:

This study has been approved by the University of Technology, Sydney Human Research Ethics Committee. If you have any complaints or reservations about any aspect of your participation in this research which you cannot resolve with the researcher, you may contact the Ethics Committee through the Research Ethics Officer (ph: +61 2 9514 9772 Research.Ethics@uts.edu.au) and quote the UTS HREC reference number. Any complaint you make will be treated in confidence and investigated fully and you will be informed of the outcome.

Appendix 3a Student Information form

UNIVERSITY OF TECHNOLOGY SYDNEY

INFORMATION SHEET-STUDENTS

THE EFFECTS OF STUDENT-ORIENTED ANIMATIONS ON LEARNING PROCESS *2012000391*

WHO IS DOING THE RESEARCH?

My name is Zeynep Polat and I am graduate student at UTS. My supervisor is Assoc. Prof. Peter Aubusson and co-supervisor is Matthew Kearney in Faculty of Arts and Social Sciences, Education.

WHAT IS THIS RESEARCH ABOUT?

This research is to find out about the impacts of student-oriented animation programs on student learning for the fundamental chemistry concepts.

IF I SAY YES, WHAT WILL IT INVOLVE?

I will ask you to take part in creating animation program for two class hours and an interview to find out about your ideas. When you are creating animation program with your partner, there will be recording program to record every step of your animation. In addition, video and audio recording will take place during creating your animation. In video recording your face will not be detected. The interview will be audio-recorded, and this recording will be turned into a typed transcript. You don't have to answer a question if you do not want to.

ARE THERE ANY RISKS/INCONVENIENCE?

There are very few if any risks because the research has been carefully designed. However, it is possible that you might me embarrassed by being video and audio recorded and to discuss your ideas with your partner during animation design process. In video recording your face will not be detected. However, the research is confidential, in other words, I will not reveal your answers to anybody. I will give you and to your school -pseudonym-a fake name. However, it is possible that some people such as your teacher may recognise your animation in the research and may recognise something from your interview.

WHY HAVE I BEEN ASKED?

You are able to give me the information I need to find out about how students create animations about the fundamental concept of chemistry. You also work as a pair in the creation of animation, I also need to find about what you are discussing with your partner and how it affects your learning process. Your answers in the interviews will also help me to really understand how the animation program help your learning and what are its impacts on you.

DO I HAVE TO SAY YES?

You don't have to say yes.

WHAT WILL HAPPEN IF I SAY NO?

Nothing. I will thank you for your time so far and won't contact you about this research again.

IF I SAY YES, CAN I CHANGE MY MIND LATER?

You can change your mind at any time and you don't have to say why. I will thank you for your time so far and won't contact you about this research again.

WHAT IF I HAVE CONCERNS OR A COMPLAINT?

If you have concerns about the research that you think I, Zeynep, or can help you with, please feel free to contact me on [redacted] or email me [redacted] or my supervisor can help you on +61 2 9514 5265 or email him Peter.Aubusson@uts.edu.au

If you would like to talk to someone who is not connected with the research, you may contact the Research Ethics Officer on 02 9514 9772, and quote this number *(give UTS HREC Approval Number)*

Appendix 3b Teacher Information form

UNIVERSITY OF TECHNOLOGY SYDNEY

CONSENT FORM-Staff

THE EFFECTS OF STUDENT-ORIENTED ANIMATIONS ON LEARNING PROCESS *2012000391*

I __________ (participant's name) agree to participate in the research project "The Effects of Student-oriented Chemistry Animations on Conceptual Learning Processes" ***2012000391*** being conducted by Zeynep Polat with phone number , and student number of the University of Technology, Sydney for her PhD degree in Faculty of Arts and Social Sciences, Education. Zeynep Polat is a UTS international research scholarship student.

I understand that the purpose of this study is to find out about the impacts of student-oriented animations on student learning for the fundamental chemistry concepts.

I understand that I have been asked to take part in creating animation program for two class hours and support students when they are creating their animations. When students are creating animation program with their partner, there will be recording program to record every step of their animation. In addition, video and audio recording will take place during creating their animation. In video recording students' face will not be detected. The interview will be audio-recorded, and this recording will be turned into a typed transcript. You don't have to answer a question if you do not want to. The researcher will treat all students and their answers with respect during interviews.

I understand that Zeynep Polat will also use pseudonyms for the schools and students will not reveal the identity of me in research publications, reports or presentations. All digital video-audio recordings and transcriptions will not be accessible to others other than Zeynep Polat and her supervisors.

I am aware that I can contact Zeynep Polat or her supervisor(s) Assoc. Prof. Peter Aubusson and Dr. Matthew Kearney in Faculty of Arts and Social Sciences, Education if I have any concerns about the research. I also understand that I am free to withdraw my participation from this research project at any time I wish, without consequences, and without giving a reason.

I agree that Zeynep Polat has answered all my questions fully and clearly.

I agree that the research data gathered from this project may be published in a form that does not identify me in any way.

____

Signature (participant)

__/__/

____

Signature (researcher or delegate)

__/__/

NOTE:

This study has been approved by the University of Technology, Sydney Human Research Ethics

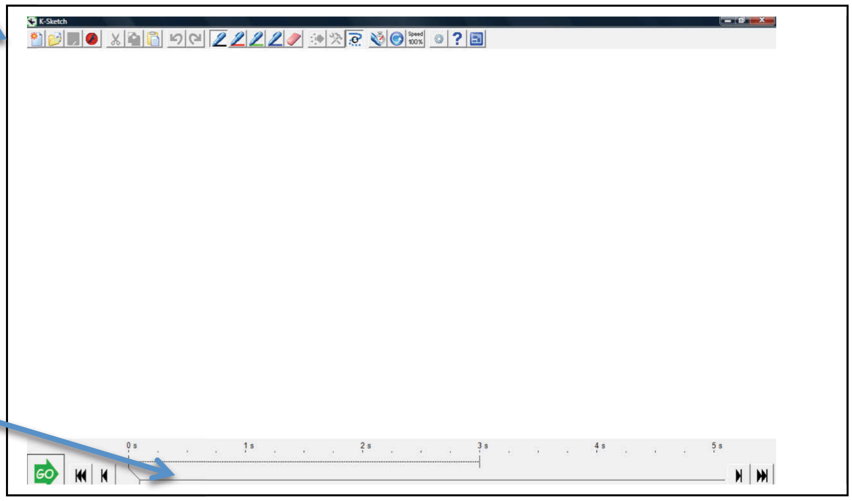
Committee. If you have any complaints or reservations about any aspect of your participation in this research which you cannot resolve with the researcher, you may contact the Ethics Committee through the Research Ethics Officer (ph: +61 2 9514 9772 (Research.Ethics@uts.edu.au) and quote the UTS HREC reference number. Any complaint you make will be treated in confidence and investigated fully and you will be informed of the outcome.

Appendix 4 K-Sketch Animation User Guide Worksheet

K-Sketch Animation User Guide

K-Sketch, kinetic sketch pad is for novice animators to create informal animations from their sketches. You can create your own animations with K-Sketch animation program. In the below, you can see K-sketch overview.

Toolbar

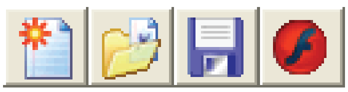


Canvas:

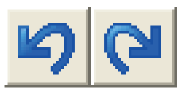
Where you will draw and view animation

Time Controls: Allow you to play your animation or move to any point in time

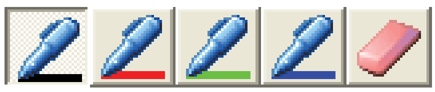
Buttons:



New Open Save Flash

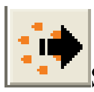


Undo Redo

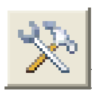


Colorful Pens Eraser

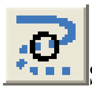
Cut Copy Paste

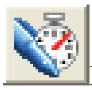


Select Next Guess

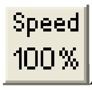


Fix Last Motion

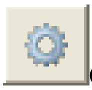

Show Motion Paths


Record Drawing


Loop Playback



Adjust Speed

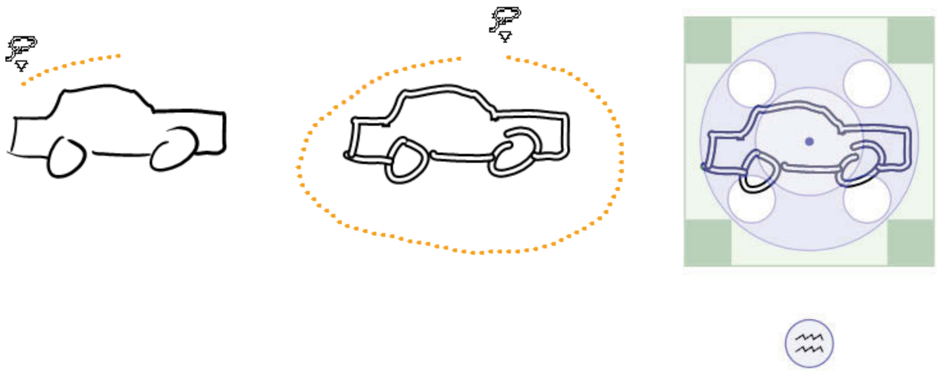

Options


Help

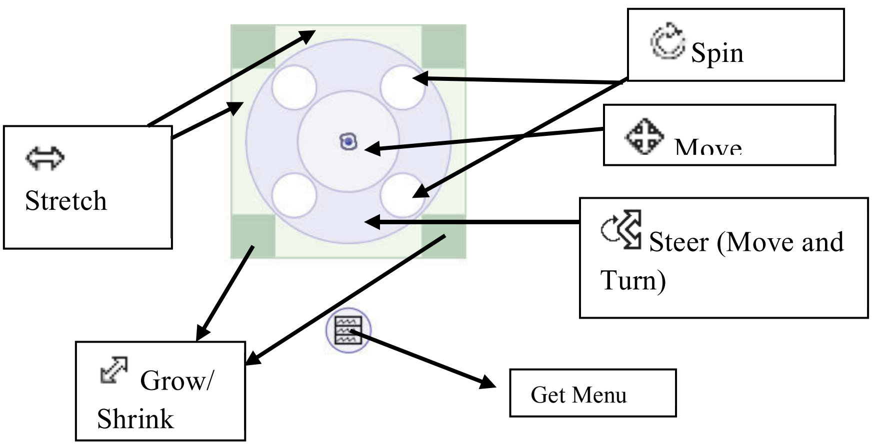

Full Screen Mod

Selecting Objects Object Handle

You can move objects in various ways, depending on where you touch. To select object, you must hold down an "Alternate" (Alt) button and draw a loop around them. When you select an object, the Object Handle appears as shown below.



Object Handle



Tutorial 1: *Count Down*

Step 1: First draw the number of 5 and move along two times with ► button in time control line.

Step 2: Take eraser and get rid of the 5 and when we erase 5 we will see the shadow of 5 as grey colour. It will help us to add the other numbers in the same place.

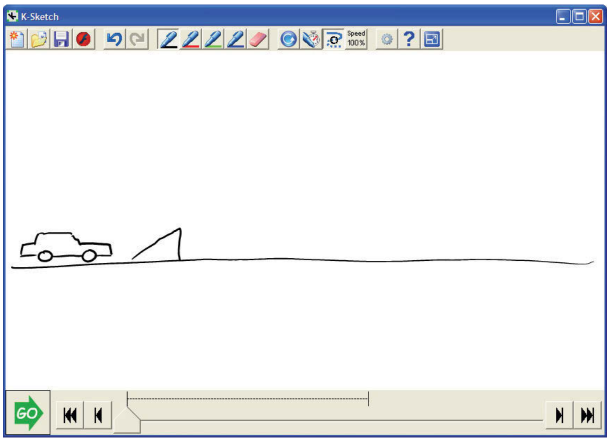
We get a pen and draw 4 in the same place and again move along two times with ► button in time control line.

Step 3: Repeat the same steps for number 3, 2, and 1 After deleting 1, lets write GO! and save with move along two times with ► button in time control line.

Step 4: Now it is time to watch your animation firstly press rewind button and than "Go" button to play the animation.

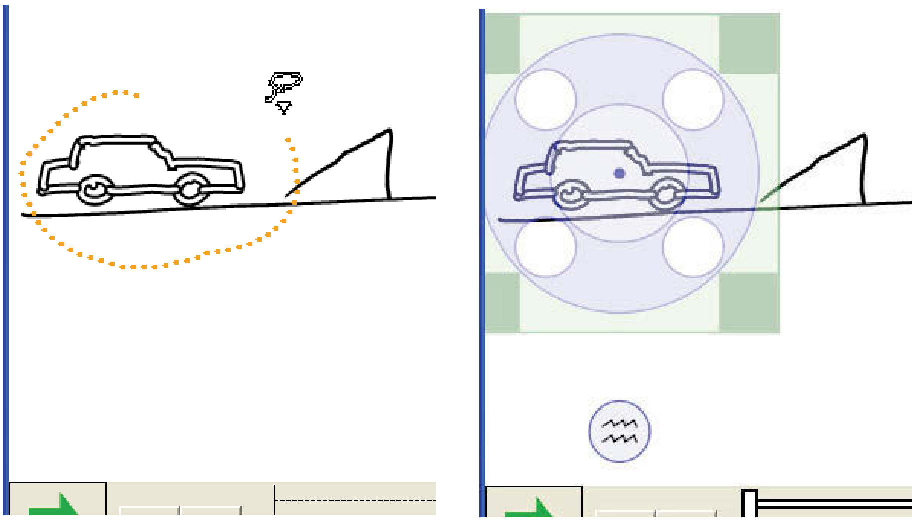
Tutorial 2: *The Car Jumped Over the Plane*

Step 1:



Start by drawing the ground, the ramp, and the car.

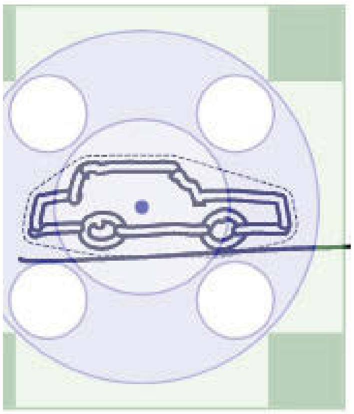
Step 2:

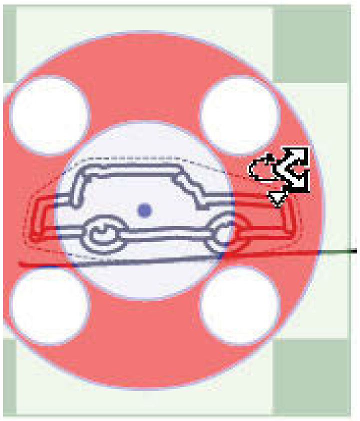


Select the car by holding an **Alternate "Alt"** button and drawing a circle around the car with the pen. When you finish, all the lines of the car should be displayed as outlines (indicating that they are selected) and the **Object Handle** should be visible above them.

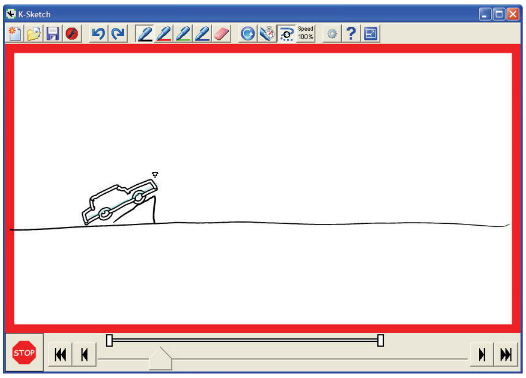
Note: To get rid of the **Object Handle,** select empty space (hold an **Alternate** button and tap the pen in a place with no ink strokes).

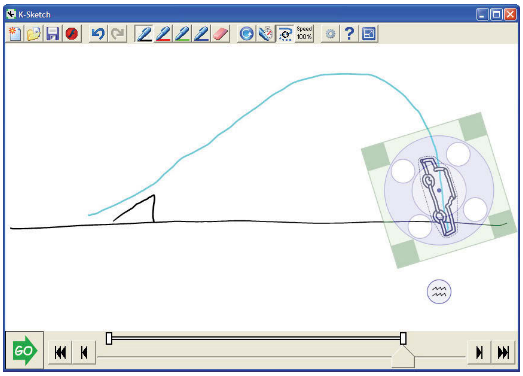
Step 3:





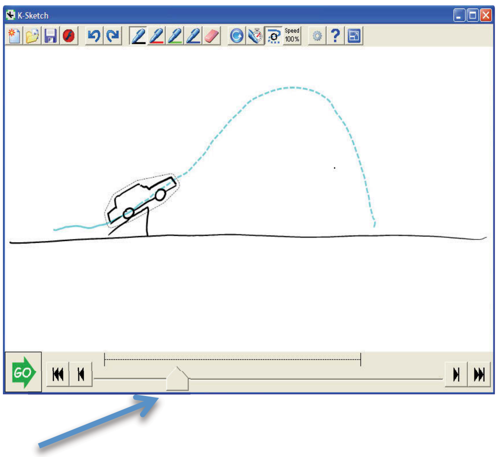
Move your pen to the **Object Handle's** "Steer" region. When you do so, the region will turn dark blue but we want to save our motion. Hold an **Alternate** button to indicate your desire to record the motion over time. When you hold this button, the "Steer" region turns red as shown above right.

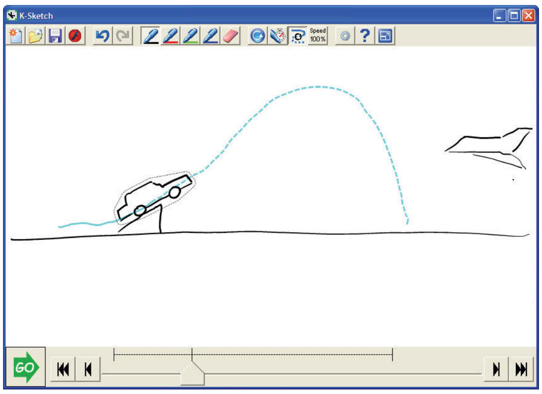




Now drag the car at a constant speed along the path shown with mouse.

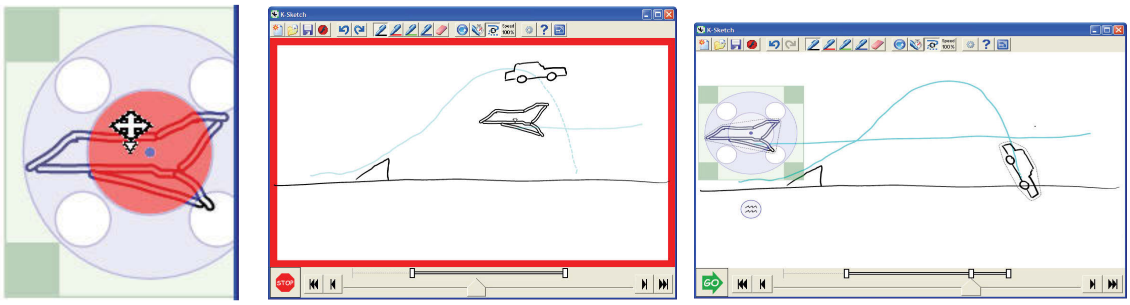
Step 4:





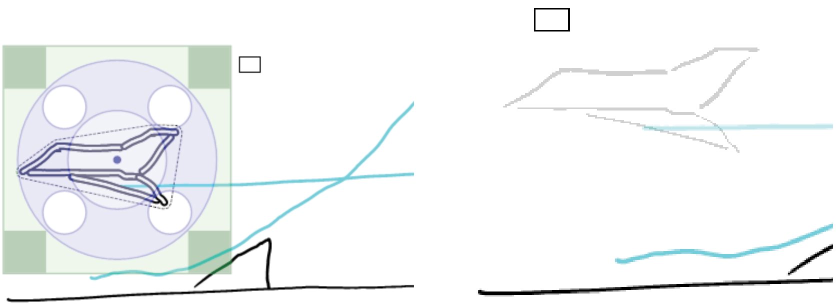
Draw the plane at the moment it appears. Move the time slider to the point shown above, when the car is on the ramp, and then draw the plane. The plane will be visible from this moment forward.

Step 5:



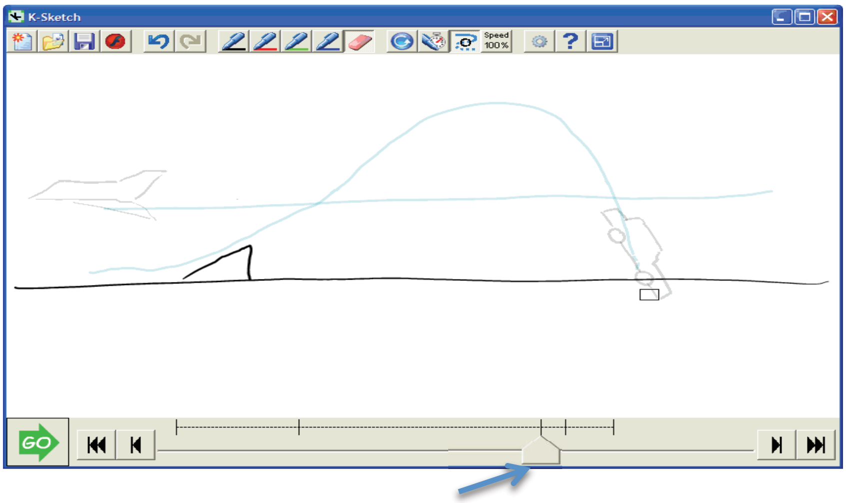
Select the plane (see Step 2), and hold the pen over the "Move" region in the center of the **Object Handle.** Hold an **Alternate** button so that this region is red, as shown above left. Then drag the plane to the left, recording its flying movement. The car moves as you drag so you can coordinate the two motions. Do your best to move the plane steadily and keep it under the jumping car.

Step 6:

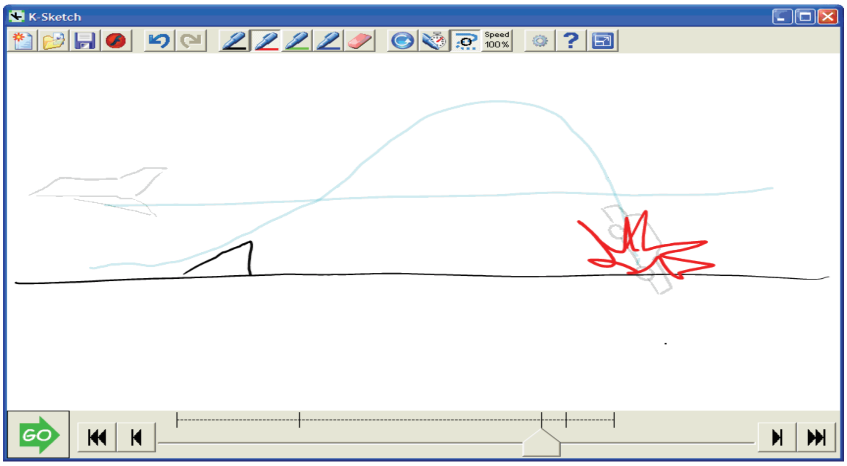


Make the plane disappear when it reaches the far left of the screen so that it appears to fly away. Select the **Eraser** (circled in red above) and erase the plane.

Step 7:



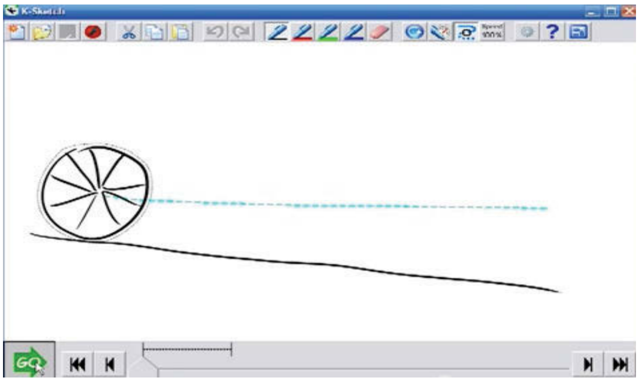
As a final touch, make the car explode when it hits the ground. Move the time slider to the end of the animation or to the moment when the car stops moving. Then select the **Eraser** and erase the car at this moment.



Finally, select the **Red Pen** and draw an explosion on top of where the car was, as above. That's the final step! Rewind and play the full animation.

Tutorial 3: *Rolling Down*

Step 1: In this animation we will learn how to copy the movement. Start by drawing a road with slope and a wheel on top of it. Then move time slider to the beginning of animation.

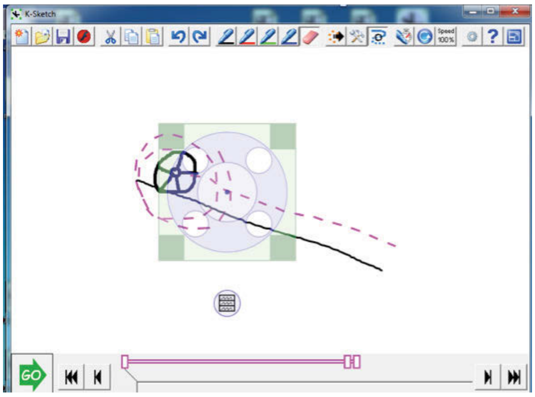


Step 2: Select the wheel and hold the pen over the "Move" region in the center of the **Object Handle.** Hold an **Alternate** button so that this region is red, then drag the wheel to the down, recording its movement. Move time slider to the beginning of animation. Unselect the wheel.

Step 3: We want that the wheel rolls down when playing. Select the wheel again hold the pen over the "Spin" region in the corner of the **Object Handle** (small circle). Hold an **Alternate** button and spin the wheel. Lets' watch what we animated until this point.

We saw that K-sketch saved only our last movement. To save also other movements (rolling down), select the "Fixed Last Motion" button and choose the movement which you want (generally it is on the left top side).

Step 4: Move time slider to the beginning of animation. Select the "Select Next Guess" button and we will see that our path became pink color.



Select the "Copy" button and drag the wheel little to down. Select "Paste" button and you will see that we copy the motion. Let's bring the copied wheel to top of the road. That's the final step! Rewind and play the full animation.

Tutorial 4: *Disappearing of Small Balls*

Step 1: Start by drawing one small ball. Hold an **Alternate** button make copy and paste from the same ball and move the ball where you want to put with the help of mouse. We can repeat this “copy paste” step until we have four balls. Then move along two times with ► button in time slider. Select “Eraser” and delete all balls and copy new balls where is close to the other balls and along two times with ► button in time slider. Let’s repeat this step 3 or 4 more times. When we rewind the animation we will see that small balls are moving.

Step 2: We want that while small balls are moving, they should be disappeared. Select one ball and hold the pen over “Move” region in the centre of the **Object Handle**.

Hold an **Alternate** button so that this region is red, then drag the ball when it reaches the far top of the screen so that it disappears from the screen. Move time slider to the moment when the ball is not disappeared. Select the ball again hold the pen over the “Spin” region in the corner of the **Object Handle** (small circle). Hold an **Alternate** button and spin the ball. To save the movement, select the “Fixed Last Motion” button and choose the movement which you want (generally it is on the left top side). Lets’ watch what we animated until this point.

Step 3: Again move time slider to the moment when the ball is not disappeared. Select the ball again hold the pen over the “Grow/Shrink” region in the corner of the **Object Handle** (small square). Hold an **Alternate** button and shrink the ball. To save the movement, select the “Fixed Last Motion” button and choose the movement which you want (generally it is on the left top side). Lets’ watch what we animated until this point. You can try this step for other balls too. Rewind and play the full animation.

Creating Your Own Animation:

Imagine an ice block in a beaker at -20°C and you can also see the particles of that ice block. Suppose that you are increasing the temperature until 100 °C and still you can see the particles. Please draw what you imagine you would see as the temperature changes.

Appendix 5 ESSA Questionnaire

Pre-Post Test:

At school, Alex investigated the heating of water using the following apparatus.

1. What is happening to the particles of water as the water is heated?

☐They are getting bigger.
☐They are getting smaller.
☐They are moving more slowly.
☐They are moving more quickly.

2. Alex found that she could not heat the water above 100°C. The best explanation is that, at 100°C,

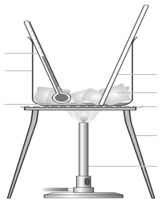
☐water particles chemically react.
☐water particles take up less space.
☐water particles turn into different particles.
☐water particles absorb enough energy to break free from one another.

3. Which process causes fog to form on a mirror?
☐melting
☐freezing
☐condensing
☐evaporating

4. When a mirror fogs up, the change of state can be shown as

☐liquid ➔gas
☐gas ➔liquid
☐liquid ➔solid
☐solid ➔liquid

❖ A science class was doing an experiment to observe temperature changes when heating ice. Each group started the experiment with four cubes of ice and a small amount of water in a beaker. They heated the beaker, with constant stirring, over a low Bunsen burner flame as shown in the diagram below. They measured the temperature every minute and recorded the results in a table.



One group of students obtained the following results.

Time (in minutes)	0	1	2	3	4	5	6	7	8	9
Temperature (in °C)	1	1	1	4	15	29	45	61	75	89

1. Using the information from the result table, describe what was happening in the first 9 minutes of the experiment.

2. Suppose that you are increasing the temperature until 100 °C and you can see the particles. Please draw what you imagine you would see as the temperature changes.

3. Using your knowledge of the particle theory, explain why this happens.

Appendix 6a Teacher Interview Questions

Interview questions for teachers

The interview will be audio recorded so that I can capture all peer discussions. However, you can ask me to turn the recorder off at any time during the interview- without giving me an explanation. I also assured that your identity and your students' identity won't be revealed in publications or to anyone else.

Introduction
Thank you for agreeing to take part in my study. Do you have any questions for me before staring?

<u>Students' learning:</u>

1. Firstly, Do you think that students exactly transferred their imaginations or thinking to their own animations?
2. Does animation creation process (including discussions before and during the animations) contribute to their previous learning or helped to learn new things about concept?
3. Does creating animations help students' understanding? How? Does the process of creation animation contribute to students' learning? How?

<u>Working in groups:</u>

4. Was working as pairs useful for students' learning? How?
5. What did students mostly discussed with their partners before starting animation? Is this discussion was useful for students? Why?
6. If students create the animations alone, would it be different? What kind of differences would be in their animations? Not necessary

<u>Teacher support</u>

7. Did you support or only observe your students while they were creating animations? What kind of support did you provide for your students?
8. Did your participation to animation creation process contribute to your teaching methods? How?

<u>Implications:</u>

9. Do you want to use student-generated animations in your teaching? How do you use animations in your classes?
10. Are animations really necessary for students to understand the…concept? What kind of other activities or teaching methods can help their thinking process and help us to understand their thinking?
11. Can students also show their imagination without drawing animations? How?
12. Was creating animations helpful for you to understand students' thinking?

Thank you for your contributions, is there any thing else you would like to talk about before you leave or is there anything you want to ask me?

Thanks again.

Appendix 6b Student Interview Questions

Semi- Structured Interview Questions (Students)

1. It was really interesting to watch your animation. How do you think that animation process goes?
2. What did you really mean in this part of your animation?
3. What does the space between particles mean? What is there between these particles? (empty space, air)
4. Do you really want to draw these spaces between particles? Why?
5. Why did you draw arrangement of the particles in this way?
6. Why the particles have different states? What makes them in different physical states? (attraction forces between the particles of matter, and the strength of these forces)
7. What does this motion show? (the particles in three states of matter are in continuous motion)
8. Why did you draw them in this shape (round, rectangular, dot etc.) or different colour (H and O molecules)?
9. Is this drawing really your imagination? Is there anything that you would like to show better?
10. What did you learn about states of the particles? Did creating animation help you for this topic? How? Can you give an example of how helped to your learning?
11. Did creating animation influence your thinking about the melting ice?
12. While you were creating your animation with your partner, did your partner influence your opinions? If yes how? Can you give an example?
13. Before start to create animation, what did you discuss with your partner? For example, did you discuss about concept of matter and get agreement and start to draw or you just talk about how to draw or you directly start to create animation without discussion and during process you talk about concepts? Did you explain to your partner about your thinking and your imagination?
14. Did you ask anything to your teacher? What did you ask your teacher? Did s/he help your learning? How? Can you give an example?

Appendix 7 RCA Principle Analysing Sheet

11-Science-B

1	Time start	Time end	Rep. Const. Code	Principle	Details	Teacher Quotes	Student Quotes
2	0:39	0:48	1a	Planning-overview	Set up the lesson format and aim of lesson is defined	We will create an ideal animation in our minds with our teacher.	
3	0:49	0:52	1a	Planing-resources	Explaining which resources will be used	Firstly, we will show each group's animation to whole class.	
4	0:52	0:56	1a	Planning-format	Instructions	Then you will make comments about each pair's animation and your teacher will guide you.	
5	1:55	2:08	2ab	Multiple representations, group representation	Representation are shown on the board	Let's watch Berkay and Ece's animation	
6	2:09	2:11	1b	Exploration-teacher instruction	Teacher calls class to discuss about animation	How this animation looking?	
7	2:11	2:13	1b	Student interaction	Doruk explain his ideas to class		Doruk: It looks very good.
8	2:13	2:19	1c 2bd	Representation construction-teacher student interaction	Teacher supports students to critique their friends' animation	1. What is very good? Which part you like more? Why you are thinking that this animation is good Doruk?	2. Doruk: Could you restart the animation please?
9	2:20	2:32	1c 2bd	Representation construction-teacher student interaction	Teacher tries to encouarge to make crituqe with other students	1. What happened Seyma? which part you like?	2. Seyma: from solid to gas the arrangement of particles changed clearly
10	2:33	2:43	1b	Representation construction-teacher instruction	Students are supported before canonical forms. Teacher critique representation	From the solid state to gas state they are well seperated and no regular arrangement. in the gas state volume increases bcause no regular arrangement.	
11	2:44	3:10	1c 2bd	Representation construction-teacher student interaction	Teacher calls class to discussion	1. Do you think that is this animation ideal? Is this animation ok? How can we improve this animation? What can add to or change in this animation to improve it?	2. Seyma: transtions should be changed. 3. Berkay: Instead of sudden shift from right side to left side to show solid to gas, it should be appear straightly on the left.
12	3:11	3:27	1b	Representation construction-student interaction	Students are asking questions to other students(whom they created the animation) to really understand the animation		1. Deniz: Actually I don't understand this last movement? 2. Seyma: yes what is this? 3. Berkay: this is gas. It is becoming gas 4. Ece: They ar moving faster their energy is increasing and they are evaporating and their regular particle arrangement is decreasing from liquid to gas.
13	4:25	4:35	2ab	Multi representations, Group representation	Representation are shown on the board	I'm opening Ahsen and Elanur's animation now. Let's watch it.	
14	4:40	4:47	1b	Representation construction-teacher student interaction	Teacher identifies key point in the animation. Some students also talking about animation.	1. They put spaces between particles. They show solid to liquid state.	2. Doruk: it is very logical actually we were thinking like this too but couldn't save it.
15	4:48	5:10	1c 2bd	Representation construction-teacher student interaction, group agrrement	Teacher calls class to discussion with her questions	1. The spaces between molecules should be increased more? 4. (Teacher reples to Berkay question): because some of the particles away when they go to gas phase. 5. (Teacher asks again:) Did they try to show particles in the microscopic level in this part of animation? 7. They increased the spaces between particles.	2. Class: Yes 3. Berkay: why they decrease he number of particles? 6. Ahsen: yes

16	5:11	6:16	1bc 2bd	Representation construction-teacher student interaction, group agrrement, adequacy of representation	Students critique animations, teacher instruct students to improve animation	1. What do you think how can we imporove this animation? 3. we observed that number of molecules was decreasing. 5. Actually, they couldn't show the spaces how they want. 7. They couldn't show the difference between liquid and gas particles in terms of spaces, gas and liquid is looking like similar. 8. What else we can add to this animation. Can we restart the animation? 10. yeah, to change state, particles need heat. 12. Yes all changes we could see together. and of course matters cannot change their state without getting heat.	2. Berkay: I think when we heat, the number of molecules should be remain same. 4. Berkay: Spaces between molecules are good but if they don,t change the molecules, it could be better animation. 6. Berkay: yes 9. Berkay: They couldn't show how we give heat. 11. Ece: Instead of drawing seperate frames for each state (Solid, liquid, gas), they could show all changes in one screen frame together. 11. Seyma: yes transitions from one stage to another not forward.(Ece and Seyma is talking in the same time. Ece is starting to talk and Seyme is talking while Ece talking) 13. Berkay: if they increase speed of animation may we could see transtions better.
17	6:17	6:28	2bd	Group consensus on representation, adequcy of representation,	Students and teacher engagige in an ongoing assessment of student representation.	1. But in this part, visualisation is better. 4. Yes, but when matter change their states, the structure of particles?	2. Berkay: it is better than urs. 3. Ece: compounds are changed over there? (class laughes) 5. Class: no no no change
18	6:30	6:44	2a	Evaluation of learning process	Teacher tries to understand what the group (creator of animation) thinking about the structure of particles by asking questions.	2. Yes, no change, I think you draw particles different from each other in each state just because you couldn't draw same on the program? 4. Because of ineffective drawing, compound turn to totally different compound.	1. Alanur: no no no change in their structure. 3. Alanur: yes yes because of not proper drawing in the animation program
19	6:56	7:35	2ab	Multiple representations, group representation	Representation are shown on the board	Lets see what Seyma and Deniz did?	
20	7:36	7:40	1bc	Representation construction-teacher student interaction .	Teacher identifies key point in the animation. Some students also talking about animation. Deniz explains concepts to class and make critiques	1. Yes they showed particules very clear.	2. Deniz: Actually, we only focus on particles.
21	7:41	7:47	1bc 2bd	Representation construction-teacher student interaction, group agrrement, adequacy of representation	Students critique animations, teacher instruct students to improve animation	2. It looks good but.. 4. yes yes, I think so.	1. Emin: I think it is very good. 3. Deniz: If we have give motion to each particle, I mean if we show each particle's own motion, it would be better.
22	7:48	8:09	1b	Representation construction-Teacher instruction	Teacher defines the properties of solid, liquid, gas	For example, in here (solid state) you can vibrate particles. In that one (liquid) you can show that particles slide past one another. You can also give different motions to gas particles, such as flowing easily or spining etc.	
30	15:30	16:11	1c 2bd	Representation construction-teacher student interaction, group agrrement	Tacher calls them to explain and discuss the animation. Students ask questions to the group which they created the animation.	1. Can you open again make it little bit slow? What we undrstood may be different than what they tried to explain. First we tell them what we understand from their animation. 7. What else? 10. Ok Doruk you explain us.	2. Ece: I understand that paricles are different in here because they are in different colors. And when they heat all of them, solid turned to gas particles more than others. 3. Doruk: I just drew it like that because this baker is bigger. 4. Ece: everything is finished very quick that is why it is hard to understand. 5. Deniz: The space between gas and liquid particles are looking like same. 6. Doruk: Deniz you don't know my drawing ability. 8. Berkay: I think what they try to draw is the same thing you requested from us to draw. 9. Seyma: I think the thing what they try to explain is same with ours but..
31	16:12	16:55	1bd, 2a	Representation construction-teacher student interaction	Doruk explains his drawing to class. Class and teacher try to understand animation.	2. We didn't understand please explain again. 5. What did you try to draw, just explain this? 7. Ok. 9. What happened while changing from solid to here? 11. I mean why you have two from this (showing solid part)? 13. It means when you heat them, they are still same? This solid is still solid, liquid is still liquid and gas is still gas? 14. Ok I got the idea now. In the begging they are already showing us solid, liquid and gas then after heating them seperately they are showing that what is happening in the each state.	1. Doruk: first we heat solids then steam has ocuured top of it then something happened, then we heat the liquid like this..3. Doruk: I didn't understand, too. 4. Class: Laughes 6. Doruk: First I heat solid. 8. Doruk: After that.. 10. Doruk: where? 12. To see more clear. These are matters and we heat them here. 14. Yes solid, liquid and gas again.
32	16:56	17:32	1cd 2d	Representation construction-teacher student interaction, adequacy of representation	Teacher supports students to critique their own animation. Student try to explain what he tries to explain.	1. It is good but there is not much difference between first and second (point to before heat and after heat drawings). 3. Ok if you had time to draw third one, how would you draw it? 5. All of them? Solid, liquid, gas? 7. Ok. 8. I think you show the things which should be with transitions, first solid, liquid, gas?	2. Doruk: Yes because we were trying to draw third one but the bell is rung. 4. We were planing more space between the particles and all would be in the gas state. 6. No, yes yes all of them would be like that. 9. Doruk doesn't replied to his teacher (bored).
33	17:42	21:51	1d, 2d, 4	Canonical explanations are given, the adequecy of representations, formative assesment	States of matter (solid, liquid, gas) are discussed. They are given as shown as representations on board.	1. What do you think about this? Solid, liquid and gas phases? 3. Do you think same? I mean before you see this animation was your thinking same? 5. Yes Deniz and Seyma wants to give this motion in the solid part. 7. How were you thinking for the liquid phase? 10. Yes. They don't have any spaces between particles. 12.They flows easily and they can slide past one another. 14. That is why soldis and liquids cannot be easily compressed, gas particles are compressible. Ok, Lets see what we have more. 15. Lets check evaporation, now. Can you see liquids? Can you see other matter too? 17. Let's look at condensation now. 18. Ok now lets see the ice block while heating. Look at here it is cold water and I'm increasing its temperature. What will happen? Can you see molecules are moving faster and they try to go further from each others. It means the phases of matter are determined by the attraction forces between the particles. In the solid phase, attraction forces are more that is why molecules are close to each other, in Liqid state it is little bit less than solid state. In the gas phases attractive forces are decreases so particles are going far away from each others so we see them as gas phases. the matter is same bec changing phases dont change the structure of matter.	2. Berkay: It is professional. 4. Seyma and Deniz: Yes, yes 6. Berkay: But I was not thinking like this for liquid. 8. Berkay: but in here there is no space between particles for liquid? 9. Ece: iiiim just vibration? 11. Berkay: It means everything was a lie, ther is no space 13. Ece: Immm of course if no space then flows. 16. Seyma: Yes we see.
34	21:52	22:28	1d	Canonical explanations are given	Example of K-Sketch animation is on board	1. What is happening, first vibration then ice block is melted and liquid then gas. Let's watch again.	
35	21:29	23:44	1b, 2bc	Representation-Instruction, Group agrrement, form and function, Representation construction-teacher student interaction	Teacher instructs class to create an ideal animation	1. Just imagine and Let's draw in our minds? 4. We watched all animations, your friends, your animation, expert animations, if we draw again what do you draw? 6. You are saying that I definetly show particles with motion. 8. What you do girls? 10: How? 14. Im sure that when you try, it would be better.	2. Ece, Seyma, Doruk: Same with the last one. This is very good. 3. Berkay: I didn't understand the question exactly. 5.Seyma: This time I show vibrations. 7. Berkay: In the gas phase, some particles go away from beaker. 9. Ahsen and Alanur: Better 11. We can make particles regularly, give motion to the particles. 13: Doruk: I cant have better drawing but I try better animation like that.
36	23:45	25:23:00	2a	Evaluation of learning process	Method of process, teacher explains the whole process.	.... 1. What did we learn while drawing? You should compare your thinking before two weeks with your thinking now. 3. Did we learn motion in particles? 6.... Berkay was thinking that liquids have spaces between their particles. 8....How we know before? solids dont have space, liquidshave some gas have more.....	2. Berkay: Imm. Actually we know the topic. 4. Class: yess. 5. Seyma: We learn the regularity of particles. 7. Berkay: yes and they flow easily. 9. Irregularity.
37	25:23:00	25:43:00	2a	Evaluation of learning process	Teacher calls class to give ideas about creating process.	1. When we imagine something, do we really need to draw them?	2. Seyma: yes yes, when we draw, it stays longer in our minds. 3. Deniz: Yes I also think like Seyma and it makes easier to share our thinking with others. 4. Ece: when we concrete (embody), it stays longer iin our minds.

38	25:44:00	26:26:00	1b	Representation construction-teacher interaction	Teacher instructs class to create an ideal animation	1. We all understand this topic isnt it? 2. When we have a new topic, do you want that we should draw first then discuss or you just want discussion session, you can understand only from discussion? Which one do you prefer? 4......you tried something, ...you saw expert animation, you compared yourself with them but i was thinking different now im thinking different...	1. Seyma: yes 3. Berkay: ...when I draw I was thinking different and now different.
39	26:27:00	26:48:00	2d	Adequacy of representations	Discussion abaout advantages and disadvantages ofcreating animations	1. Ok we did animations and we said they are good. Now Lets discuss their strong and weak sides. 3. Do we trust all animations? ...we are just asuuming something like round balls they are just modelling actually they are only models ....4. it is taking time. Could you learn the same concept without spending that much time?	2.. Berkay: Theya re professional but not explanatory. 5. Doruk: No 6. Emin: Actually when it is compared the other computer programs, this program is taking less time.
40	27:49:00	28:13:00	2ad	Evaluation of learning process, Consesus about animations	Students respond the teacher and discuss	Could we learn every concept with animation?	2. Class: noo, mole? 3. Ece: May be the mathematical things we cant learn but for the others it more (kalicili) stays more in our long term memory.
41	28:14:00	28:44:00	1c	Canonical explanations are given	Telling about micro macro level		
42	28:45:00	29:26:00	2ad, 4	Evaluation of learning process, Consesus about animations, formative assessment	Students respond the teacher and discuss	Let's Mention about its advantages more. Compare with other animations which you watched before.3. While doing something by urself, what is happeneing? 5. you can see your mistakes visually isnt it?	2. Seyma: I think this is really useful because we create something by ourself and see with eyes, we proved them to ourself. 4. Seyma: We are learning more. It stays in our minds longer and we can say ahaaa I did this one like this so I know it we are realizing something easier. 6. Seyma: yes we saw our mistakes virtually.
43	29:27:00	30:10:00	2a	Evaluation of learning process	Method of learning in follow up class	1. What about if we don't make this follow up discussion lesson? 4.. Mentions multiple representations 6. And you know in normally, you are learning how you imagine but here we discussed....	2. Seyma: May be misconceptions would be stayed in our minds we cant make corrections 3: Berkay: We learnt the most correct one. 5. Ece: I think the education system should be like this. 7. Seyma:I really enjoyed. First: imagine then create then discuss.
44	30:11:00	30:20:00	2ad	Evaluation of learning process, adequecy of representations	Teacher tries to encouarge to make criticism for the evaluation of learning process	1. Alanur and Ahsen what r u thinking? 3. You are thinking then when you were creating your animation it is staying in yoir mind longer?	2. Alanur: We are also thinking same. 4. Alanur: In this way we don't forget easily (kalici)
45	30:21:00	32:21:00	4	End of Lesson, formative assessment	Teacher mentions about the process. Students tell their openions about creating animations.	.....2. For example Ece, after this study, when you go to your home, do you create a new animation? 4. ooh really? In which topic and what do you want to draw? 8. I think animation will also affect other things in your life.	1. Ece: I think we have privilege because we can draw and create something noe so we shoul always prefer drawing. 3. Ece: yes. 5. Firstly, I will try to draw the last animation which is shown on board, and other topic which I just imagine but not sure whether my imagination is correct or not. 6. Berkay: If I draw something I dont draw something related with chemistry. I try to create cartoons. 7. .....(Student are talking about what they tried to draw at home) 9. Class: yes

11-Science-A

	Time start	Time end	Rep. Const. Code	Principle	Details	Teacher Quotes	Student Quotes
1	Time start	Time end	Rep. Const. Code	Principle	Details	Teacher Quotes	Student Quotes
2	0:39	0:48	1a	Planning-overview	Set up the lesson format and aim of lesson is defined	We will create an ideal animation in our minds with our teacher.	
3	0:49	0:52	1a	Planing-resources	Explaining which resources will be used	Firstly, we will show each group's animation to whole class.	
4	0:52	0:56	1a	Planning-format	Instructions	Then you will make comments about each pair's animation and your teacher will guide you.	
5	1:55	2:08	2ab	Multiple representations, group representation	Representation are shown on the board	Let's watch Berkay and Ece's animation	
6	2:09	2:11	1b	Exploration-teacher instruction	Teacher calls class to discuss about animation	How this animation looking?	
7	2:11	2:13	1b	Student interaction	Doruk explain his ideas to class		Doruk: It looks very good.
8	2:13	2:19	1c 2bd	Representation construction-teacher student interaction	Teacher supports students to critique their friends' animation	1. What is very good? Which part you like more? Why you are thinking that this animation is good Doruk?	2. Doruk: Could you restart the animation please?
9	2:20	2:32	1c 2bd	Representation construction-teacher student interaction	Teacher tries to encouarge to make crituqe with other students	1. What happened Seyma? which part you like?	2. Seyma: from solid to gas the arrangement of particles changed clearly
10	2:33	2:43	1b	Representation construction-teacher instruction	Students are supported before canonical forms. Teacher critique representation	From the solid state to gas state they are well seperated and no regular arrangement. in the gas state volume increases bcause no regular arrangement.	
11	2:44	3:10	1c 2bd	Representation construction-teacher student interaction	Teacher calls class to discussion	1. Do you think that is this animation ideal? Is this animation ok? How can we improve this animation? What can add to or change in this animation to improve it?	2. Seyma: transtions should be changed. 3. Berkay: Instead of sudden shift from right side to left side to show solid to gas, it should be appear straightly on the left.
12	3:11	3:27	1b	Representation construction-student interaction	Students are asking questions to other students(whom they created the animation) to really understand the animation		1. Deniz: Actually I don't understand this last movement? 2. Seyma: yes what is this? 3. Berkay: this is gas. It is becoming gas 4. Ece: They ar moving faster their energy is increasing and they are evaporating and their regular particle arrangement is decreasing from liquid to gas.
13	4:25	4:35	2ab	Multi representations, Group representation	Representation are shown on the board	I'm opening Ahsen and Elanur's animation now. Let's watch it.	
14	4:40	4:47	1b	Representation construction-teacher student interaction	Teacher identifies key point in the animation. Some students also talking about animation.	1. They put spaces between particles. They show solid to liquid state.	2. Doruk: it is very logical actually we were thinking like this too but couldn't save it.
15	4:48	5:10	1c 2bd	Representation construction-teacher student interaction, group agrrement	Teacher calls class to discussion with her questions	1. The spaces between molecules should be increased more? 4. (Teacher reples to Berkay question): because some of the particles away when they go to gas phase. 5. (Teacher asks again:) Did they try to show particles in the microscopic level in this part of animation? 7. They increased the spaces between particles.	2. Class: Yes 3. Berkay: why they decrease he number of particles? 6. Ahsen: yes
23	7:41	7:47	1bc 2bd	Representation construction-teacher student interaction, group agrrement, adequacy of representation	Students critique animations, teacher instruct students to improve animation	1. Bence animasyon gelistirilebilirdi,. Ne yapsak daha iyi bir animasyon haline gelirdi? 3. Ne yapmak istediniz de yapamadiniz? 6. Tanecikleri hareketlendirimiydik?	2. Mirac: Hocam mouseumuz yoktu ondan. 4. Enes: Hocam kaynatabilirdik. 5. Mirac: Atesler oynayabilirdi 7.Haocam katilar hareketlenmezdi gazlar hareketlenebilirdi. Sivilar da immm biraz hareketlenebilirdi.
24	6:17	6:28	1b, 2bd	Representation construction-student interaction, Group consensus on representation, adequcy of representation,	Students and teacher engagige in an ongoing assessment of student representation.	1. Sen ne diyordun cagatay? 3: Neresi hareketli olsaydi? 5. Bir de su var mi? Mesela gaz haline gecerken tanecik sekil degistirmis. Boyle bir sey olur mu? Biraz kuculmus dedin degil mi Mirac molekullerin kuculdugunu dusunuyorlarmis. Baska yorum yapmak isteyen var mi?	2. cagatay: ben sey diyordum cok guzel cizmisler sadece hareketli olsaydi. 4. Cagatay: MEsela o sivi halden gaz haline ve hem molekullerin hem de hafiften buhar ciktigini gosterselerdi hareketli olarak daha guzel olabilirdi.
25	9:55	10:04	2ab	Multi representations, Group representation	Teacher tries to open group.animations. Representation are shown.	1. who is left? 3. Mert ve Helin (acilmiyor) 6. Bir dakika cagatayinkini acalim sonra ben sizinkini tekrar deniyecegim. 3 grup kaldionlari da kaydedelim hemen.	2. cagatay: Hocam benimki cok guzel oldu ama gecislerde sorun oldu kafayi yiyecem. 4. Class: Laugh (bec empty) 5. Helin: Hocam biz size dedik acilmiyor diye ama kaydettik. 7. Aysenur: Hocam onlar mesafeyi kisaltmis cok hizli geciyor ondan yoksa aciliyor. Hemen geliyor bir daha gidiyor.
26	10:05	13:23		Exploration	Teacher gives order to watch animation from student's laptop	1. Tamam bilgisayarinizdan acin. Tut ordan Mert. Herkes goruyor mu? Arkadaslar herkes Mertin animasyonunu goruyor mu?	
27	13:30	14:50		Exploration	Student are opening their animation		1. Cagatay: Gormuyorum. Tamam gordum.
28	14:51	15:02	1b	Representation construction-teacher instruction	Teacher calls animation creator group to discussion	1. Simdi anlat bize Mert ne yaptigini.	2. Mert: Hocam burda kati, sivi ve gazi cizdik. Maddelere burda isi vermedik ama isi vermis gibi anlatayim. Burda molekuller kati oldugu icin erimedi. Burda da sivi.
29	6:30	6:44	2a	Evaluation of learning process	Teacher tries to understand what the group (creator of animation) thinking about the structure of particles by asking questions.	1. Bir daakika ben anlamadim kati, kati oldugu icin	2. Mert: Kati oldugu icin erimedi. Arasinda molekuller oldugu icin isi verdik (ama isiyiyi veremedigimiz icin pek ne oldugu anlasilmadi) sivida da hocam ayni sekilde sivida buharlasma oldu isi verdigimiz icin.
30	8:10	9:30	1bc 2bd	Representation construction-teacher student interaction, group agrrement, adequacy of representation	Teacher call some students to crituque for matching and dismatching properties of the animation.	1. Bir seysoylicem, sivi hallerinde tanecikler arasi cekim kuvvetikati hallerinden daha fazla.3. Cunku katilar arasinda bosluklar daha fazla? 5. Evet Mert kati halde tanecikler arasindaki boslugun sivi halinden daha fazla oldugunu soyluyor arkadaslar. Dolayisiyla kati halde tanecikler arasindaki bosluk sivi halden daha fazla oldugunu dusnuyormus. Dolayisla kati taneciklerin arasina bosluk birakmis. Sivi tanecikleri birazcik daha yakin cizmis.	2. Mert: Evet 4. Mert: evet hocam
31	6:17	6:28	1b, 2bd	Representation construction-teacher instruction, Representation construction-student interaction, Group consensus on representation, adequcy of representation,	Students and teacher engagige in an ongoing assessment of student representation. Teacher defines some key points	1. Dogru mu yaklasmis arkadaslar? 3. Evet neden? (silent) Cunku maddenin kati halinde tanecikler arasinda mesafe yok denecek kadar az. Ama Mertin dusuncesi onemli. Mert kati halde tanecikler arasindaki boslugun daha fazla oldugunu dusnuyormus. Evet gaza gittikce	2. Class: Yanlis hocam.
32	8:10	9:30	1bc 2bd	Representation construction-teacher student interaction, group agrrement, adequacy of representation	Teacher call some students to crituque for matching and dismatching properties of the animation.	3. Peki Mertin animasyonu icin soylemek istediginiz bir sey var mi? 5. Onu gectik. Onun disinda? 7. Dusncesi yanlis? Hani animasyon;a gorsel olarak...9. Tamam Mert tesekkur ederiz.	1. gizem: Hoca gazda normalde tanecikler arasi bosluk fazla olmasi lazim ama onlar 2. Mert: yok ama ben gazi belli olsun diye boyle yaptim.4. Mirac: Hocam dusuncesi guzel ates verseydi. 6. Mirac: Dusuncesi yanlis bence 8. Aysenur: Ben sey gordum kati ve sivinin birlesimini gaza vermis. Bence guzel olmus bakin cok mantikli olmus.

33	17:42	21:51	1d, 2d, 4	Canonical explanations are given, the adequecy of representations, formative assesment	States of matter (solid, liquid, gas) are discussed. They are given as shown as representations on board.	1. evet arkadaslar kendi animasyonlarimiz tartistik eksik ve dogru yanlari hakkinda kararlar verdik. Kendi animasyonlarimiz uzerindeki tartismamizi bitirdik. Simdi birkac tane uzman animasyonu gosterecegiz. Uzman animasyonlari hakkinda ne dusunuyorsunuz. Sizin animasyonlariniza yakin mi siizn animasyonlarinizdan farkli mi? Onlar daha mi iyi yapmislar bir bakalim. Evet ne goruyoruz burda maddenin kati, sivi ve gaz hallerini.Hangisi kati hali?3. evet bu maddenin kati sivi ve az hali. Nasil yapmislar? Ne dusunuyorsunuz animasyon hakkinda kim konusmak istiyor> Evet Serra 5. Senin cizdiginle?7. Profesyonelligi nerede neresi hosuna gitti? 9. Taneciklere hareketlilik vermis olmasi. 11. siz katilarda hareketlilik vermemistiniz. 13. taneciklerin hizlandirilmasi15. Evet baska. Evet Mirac. 17. Evet titresim halini cok net gorebiliyoruz degil mi? Kati halde de tanecikler hareket halinde birbirlerine titreyerek hareket hallerini devam ettiriyorlar. 19. evet biz oyle biliyordk evet katilarin hareket etmedigini birbirlerine bagli oldugunu biliyorduk . Ama kati taneciklerin de hareket ettigini goruyoruz. GAz taneciklerihakkinda ne diyorusnuz arkadaslar? Niye daha hizli hareket ediyorlar? 21.Aralarinda bosluk daha fazla . Aralarinda bosluk daha fazla olmasi neyi gosteriyor?23. evet birbirlerinden kopmus enerjileri yuksek oldugu icin daha hizli hareket ediyorlar. BAska bir animasyona bakalaim ama oncelikle burda hosunuza gitmeyen bir yan var mi?	2. Enes: En bastaki 4. Serra: Tanecikler arasi bosluktan bahsetmisler. 6: Serra: Benim cizdigime yakin ama biraz daha profesyonel. 8. Serra: Hareketliligi 10: selin: biz katilarda hareketlilik vermemistik. 12: serra: biz kati halden sivi hale donusurken 14. Serra:Bir de sekil halinde arasindaki bosluklari gostermistik ama hareketi gostermemistik. 16. Hocam kati halde bosluk tanecikler arasinda yok denecek kadar az sivida daha fazla gazda daha da fazla ama burada kati halde taneciklertitresiyor sivi halde daha fazla gaz halinde daha fazla.18. Sera: biz sivilar arasind HIC BOSLUK OLMDIGINI GOSTERDIK BU ANIMASYONDA.20. class: Aralarinda bosluk daha fazla 22. Burak: Sanki birbirlerinden kopmus 24. Bence gayet guzel kendi yaptiklarimiza bakinca bu gozumuze daha guzel geliyor.
34			1d, 2d, 4	Canonical explanations are given, the adequecy of representations, formative assesment	Evaporation and condensaton are discussed.They are given as shown as representations on board.	1. O zaman baska bir taneye gecelim simdi. Bu da yogunlasma deneyi. Burda ne dusunuyorsunuz? Bir daha izaleyelim. Gaz tanecikleri sividan koptular.3. Once buharlasti degil mi arkadaslar? Evet tanecikler once sividan kopup diger bardaga gectiler sonra bardagin yuzeyine tutundular. Sonra tekrar sivi hale gectiler. Animasyon nasil? 6, Napiyorlar? 8. Evet sividan koptular buharlastilar. Sonra 10. Evet bardagin ceperine yapisip soguyor tekrar. 12. Sen olsaydin bunu nsil yapardin? Siz olsaydiniz nasil? Yogunlsmayla ilgili animasyonda ne dusundunuz? z onceki uzman animasyonunda bizim yaptigimiza benzer haldeydi ama biz orda neyi gorduk katilarin hareket halinde oldugunu gorduk. Bu animasyonu biz yapiyor olsaydik, siz yapiyor olsaydiniz tek basiniza ne yapatrdiniz? 14. KApatmasaydin da ucar giderdi. 16. bu kadar detayli gosteremezdin. .	2. Serra: Bu sefer tanecikler birlesiyorlar. 4. Muhammed: Basarili 5. Mirac: Sivilar once kopuyorlar sonra bir daha birlesilyorlar. 7. Muhammed: Kpouyr;ar en ilk 9. Muhammed: Sonra bir daha 11. Muhammed: Siv hale geciyorlar 13. Ben en ilk isi verirdim. Isi verdikce buharlasmasini saglardim. Ama o seyi kapatmazdim. 15. Mirac: Evet ucar giderdi. 16. Class: laugh 17. Serra: Ben kapali kaldiginda sadece taneciklerin buharini gosterirdim bu kadar detayli gosteremezdim.
35			1d, 2d, 4	Canonical explanations are given, the adequecy of representations, formative assesment	Particles in hot and cold water are discussed. They are given as shown as representations on board.	1. Baska bir taneye gecelim o zaman. Suanda soguk bunu birazcik isitirsak ne oluyor. Molekullerin hareketlerine bakin.4. Sonra ne oluyor. Tanecikler hareket haline geciyor. 7. Evet hizlari artti enerjileri artti. Sividan gaza gecerken siz neyi gostermistiniz peki? 9. Tek tek tanecikleri yukari cekmisler degil mi? 11. Tanecigi sividan cikarip yukariya cekmistik ama yukari cikarken de tanecigin harekeli oldugunu artik gorebiliyoruz. Ters yone soguk suya dogru ne oluyor hareket yavasliyor.	2. serra: Hizlaniyor. 3 Burak: Hocam gaz fazina geciyor. 5. Burak t: Aralarindaki bosluk acilmis. 6. Burak: Aralarindaki bosluk artiyor sonra gaz haline geciyor. Daha fazla enerjileri oldu. 8. Mirac: Biz tanecikler boyle titrestirmemistik ya da biz sadece altten isi vermistik o sekilde gostermistik. Hareketsiz gostermistik. 10. Mirac: evet
38	21:52	22:28	1bc 2bd	Representation construction-teacher student interaction, group agrrement, adequacy of representation	Teacher call some students to crituque for matching and dismatching properties of the animation. Examples of K-sketch animations are on the board	1. Bir tane daha. Bu animasyonda begendiginiz begenmediginiz yanlar nelerdir? 3. Baska 5. Kafanizi mi karistiriyor. 8. Serra aslinda guzel bir noktaya degindi. 11. sinif oldugu icin sanirim siz buzu oda sicakligina getirdiginiz zaman isi almasina gerek yok. Disaridan ektra isi vermeye gerek yok. Zaten oda sicakligina geldiginde kendi kendine gaz haline gecti (gaz degil aslinda ogretmen yanlis soyluyor mirac farkediyor). 10. Gaz haline daha yavas gececekir. Isis verirsen daha hizli olur. Bak simdi su hali kati eridi sivi hala gecti ve sivisindan koptu. Tanecikler gaz haline gecmis ama demekki gaz halindeki bosluklari daha cok hayal ettimiz icin daha cok sivi halinde gibi gorunuyor. 12. Gosterdi zaten. 13. Gizem sen hic konusmadin? Kendi animasyonunla bu izlediklerniz arasindaki fark? Ne ogrendin? 15. Bir daha cizersen kendi animasyonun gibi mi cizersin? Yoksa? 17. Bir daha cizseler daha iyisni cizecegini dusnuyorum. 19. Evet mouse olmadigi icin zorlanmistiniz. 21. Onceki yaptiginizdan daha iyi olurdu. Peki nasil eklemeler yapardiniz?	2. Beyza: Isi verilebilir 4. Burak: Atomlarin sayisini cok fazla yapmis.6. Mirac: En son hali gaz hali degil mi bu? Gaz halinde tanecikler hala birbirine yakin, ayri yapmaliydi hepsini 7. Serra: zaten ayrisiyor. Isi vermeden ayrilmasi imkansiz gostermesine gerek yok. Olsa da olmasa da zaten isi alarak. 9. Buharlasma? 11. Beyza: Belki siviyi da gosterebilirdi. 14. Gizem: Ben sadece kendi hayal ettiklerimi yaptim. Bu daha usttu farkliydi yani iki animasyon benimkiyle bu. 16. Gizem: Boyle cizerdim heralde. 18. Mirac: Bizim mouse yoktu. 20. Serra: Gorduklerimize gore kendi animasyonumuza eklemeler yapardik hem daha iyi olurdu. 22. Ben eksiklerimizi soylemistim. Basta da molekullerin titresimi onu kesinliklle yapardim. Daha net gorunurdu. 23. Miracin yani: Ben gecen hafta yoktum ben bunlardan daha guzel yapardim.
45	28:45:00	29:26:00	2ad, 4	Evaluation of learning process, Consesus about animations, formative assessment	Students respond the teacher and discuss	1. Herkes bir kac kelime soyleyebilir mi ne katti size? Hepiniz konusun cunku hepiniz cizdiniz.	2. Aysenur: bizim kendi animsayonumuz uzman animasyonundan cok farkli cunku biz maddenintanecikli hallerini gostermemistik butun olarak buzu (yani micro) sonra siviya tanecikleri gostermedik ama simdi ogrendik izleyince. Arkadaslarimizin yaptiklarindan da yanlislarimiz ve dogrularimizi
46	29:27:00	30:10:00	2a	Evaluation of learning process	Method of learning in follow up class	1. Elestirel gozle bakalbildini. Evet sen ne dusunuyorsun? Yani surec sana ne katti? Ya da bir sey katmadi da diyebilirsin. 3. Mesela ben dersleri islerken araya anmasyon kattigimda size etkisi olur mu? 5. Mesela enerji konusunu isliyorum onunla ilgili bir animasyon izlettim.	2. Gizem: yok katti ogrendim 4. Class: olurdu 6. enes, mirac serra: Cok iyi olur. 7. Mirac: Animasyonla daha iyi anlayip ogreniriz. 8 Serra: Gorsellik akilda daha fazla kaliyor.
47	30:11:00	30:20:00	2ad	Evaluation of learning process, adequecy of representations	Teacher tries to encouarge to make criticism for the evaluation of learning process	1. Fazla kaliyor evet insan gordugunu daha az unutuyor. ama zaten tahtada slaytla zaten gosteriyoruz sekil de oluyor. 3. Animasyonla bir sey canlandirilmis oluyor degil mi? Anlatmak istedigimiz seyin canli hali oluyor. Mesela ben size animasyonla ders anlatsam ben olsaydim nasil cizerdimi dusunur musunuz? 6. Dusunurken de konun ayrintilarini kafanizdan gecirdiniz. Konuyu ogrenmenize daha fazla katkisi olabilir.	2. Burak: Animasyon daha iyi hocam. 4. Selin : sevet 5. Burak, mirac: evet
48	28:45:00	29:26:00	2ad, 4	Evaluation of learning process, Consesus about animations, formative assessment	Students respond the teacher and discuss	1. Yani kendi cizimlerinizin size kalicilik sagladigini mi dusunuyorsunuz? 3. evet baska anahtar kelime bulalim kalicilik? 5. Mesela muhammed daha cok dusundun mu? 7. Bu animasyonu yapmak seni dusundurdu mu? 9. Ilk dusundugunle son dusundugun arasinda fark oldu. 11. dusunmeye itti sizi. 13. Bir yaninizi kesfettiniz mi? KEndi yaptiginiz daha iyi verimli oldugu yanini kesfettiniz mi? 15. Bir seyi eger kebdin yaparsan kendin dusunursen onun hayatinda daha kalici bir etki yaptigini 17. Animasyon da benzer 19. evet deney gibi labda kendi yaptigimiz deney nasil bizde kalici bir etki yaratiyorsa animasyonda deneyin daha teknolojik yani.	2.class: evet 4. Miracin yani: mesala baska bir konuya yardimci olabilir 6. Muhammed: tabi dusundum 8. Muhammed: Kendimi nasil ifade edecegimi dusundum kendimi ifade ettikce animasyonun kalitesi yukseldi. 10. muhammed: Ilk dusundugumle son dusundugum arasinda fark oldu. 12. Serra: daha iyi anladik. 14. Mirac: dusunduk. 16. Miracin yani: mesela burda okuyoruz deneyini yapiyoruz animasyonda onun gibi. 18. Miracin yani: fotograf gibi ama fotografta anlasilmiyoranimasyonu kendimiz yapinca kavrayabiliyoruz.
49	30:21:00	32:21:00	4	End of Lesson, formative assessment	Teacher mentions about the process. Students tell their openions about creating animations.	1. Animasyondaki avantajiniz ne deneyde yapamadiginiz goremediginiz seyleri de kafanizda canlandirabiliyorsunuz. Baska bir sey var mi? Keske katilmasaydim bana bir katkisi olmadi diyen var mi? Cogunuz iyiki katildim diyor hic katilmasam da cok bir sey farketmezdi diyen? 3. Sen eksigini kapadin peki tartisma dersi? 5. Animasyonda birden cok dusunceyi ayni anda gorebildik tartisma ortaminda. 8. Yani senin icin hareketi zaten kafanda canlandirmistin yani animsyonlarda gordugun her sey senin kafanda ayniydi? Peki animasyona yansitanbilidin mi?	2. aysenur: benim bildigim bir programdi daha once de animasyonlar ciziyordum o yuzden cok degisiklik yok ama burda daha uzman burda 4. Aysenur: Evet elestirebildik kendi yaptigimizla arkadasimizin arasinda ne kadar fark oldugunu gorduk., farkli seyler dusundugumuzu gorduk. 6. Mirac: Yanlislarimizi duzelttik. 7. Talha Burak: Bana animasyonun hic bir etkisi olmadi. Tanecikleri biliyordum bir etkisi olmadi. 9. Talha Burak: Evet yansittim ama benim icin gereksizdi.

Appendix 8 ESSA Marking Guideline

Marking guidelines – Heating Ice

Concept being tested: Application of the particle model in a given context

First cycle : Description of observations
Second cycle: Application of particle model

Level	Codin	Features	Samples of student responses
	NA	No attempt	
l	0	• meaningless attempt	• *In the first 9 minutes of the experiment it went up in ones.* • *It was starting to change a fair bit.*
u	1	• change of state (ice melts / solid changes to a liquid) • identifies one trend in the temperature data (at first the temp stays the same / stays the same for the first 2-3 minutes / it heats up (rapidly) after 3 minutes / temperature rises / it gets hotter) • one (or more) temperature / time points)	• *Temperature is increasing. It has increased until the temperature was 89° C* • *There is not much difference in the first two minutes but then after a period of 3-9 minutes the temperature increases* • *After 9 minutes it is 89° C*
m	2	• at least two u elements OR • identifies the two trends (but misses stating the link to all the ice having melted)	• *In the first 9 minutes the temperature rose from 1° C to 89° C. This happened because the flame heated the water and melted the ice cubes* • *The temperature stayed the same for the first two minutes. Then it quickly got much hotter in every minute*
r	3	• makes an explicit connection between ice melting and the temperature beginning to rise / change	• *This happens because the ice has to melt first before it can start heating up* • *In the first 9 minutes...the temperature was rising. It stayed the same for two minutes but after three minutes the temperature was rising more than 10° C per minute...After all the ice was melted the water...become hotter.*
U	4	• heat increases the movement of particles • heat increases the movement of particles in a liquid • heat causes particles in solid to vibrate (faster) • particles spread apart when ice changes to water • heat is absorbed by ice particles as the ice melts	• *The particles in ice are not moving but when you heat it the ice starts to melt and particles can move around* • *Particles separate when it gets hotter so since the temperature rose the particles separated and became water* • *The heat gives the ice particles more energy so they move around more* • *the heat can break the energy holding the particles together in ice*
M	5	• At least two U elements (NOT if they combine the first dot point with either the second or third one (they have to distinguish the two kinds of motion)	• *When the particles are frozen, they stick to each other but when heat is added the particles move away from each other and move around. Therefore it goes from ice to water.* • *As a solid is heated, the particles start to vibrate. They vibrate more and more vigorously until the particles brake apart and start to roll around. When all the particles are rolling around, the solid has become a liquid.*
R	6	• A cause and effect explanation for change of state and subsequent rise in temperature	• *When heat is first added, it is used to overcome the strong forces of attraction holding the particles in ice together. The particles vibrate faster and faster, until they have enough energy to separate out and start moving around. At this point the ice is melting to form water. Then as more heat is added, the particles move even faster and the temperature of the water rises.*

Key Terms

This section provides an explanation of several key words and terms used in this thesis.

Analogy is a comparison between two concepts to define abstract one in familiar terms. An analogy has two attributes: the base and the target. The familiar concept is called the base analog, and the unfamiliar one, which is to be explained, is called the target analog. Analogical mapping is a process of identifying attributes of the analogy and analysing of the match and mismatch of base and target attributes.

Animation is a way of making movies by using slightly different pictures that create the appearance of movement when adding the pictures quickly in a series. Student-generated animations are animations made by students to represent their understanding of a concept.

Cooperative learning is a kind of small group instruction in a social setting in which students work together on activities or given tasks.

Essential Secondary Science Assessment (ESSA) is a science assessment program in NSW, Australia. It is based on the Years 7–10 science syllabus.

The FAR guide (Focus-Action-Reflection) is a three-stage process that informs the use of teaching analogies (see Section 2.2.3).

The Kinetic Molecular Theory (KMT) categorised the five postulates that emphasizes the movement of particles (see Section 4.2.4)

Mental models are visual or abstract representations of reality that people develop as a result of their own observations or experiences.

Misconception is view or opinion that is incorrect because of faulty thinking or understanding.

My dear teacher is a standard expression used by Turkish students in the classroom environment with their teacher.

Partner interaction refers to the dialogues between students when they are actively working with their partners or within groups to create a chemistry animation using the K-sketch animation program.

The representation-creation pedagogy intervention involved the four phases: Phase 1, training in the software program; Phase 2, creating animations; Phase 3, class discussions; and Phase 4, reflective discussion with a teaching sequence (see Chapter 3).

The states of matter refer to three traditional distinct forms of matter: solid, liquid and gas. The fourth state, plasma state was not included in this study.

The zone of proximal development (ZPD) is a zone where learning occurs in a supportive learning environment when a more knowledgeable other (MKO), who has a higher knowledge or better understanding than the learner, provides scaffolding to the learner. The MKO is a usually the teacher in the classroom environment (see Section 2.2.1).