Representing Earth Science Concepts Using Slowmation: Influences on Middle School Students' Conceptual Change

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Abstract

A number of challenges are currently impacting the quality of Earth science education in Australia. These include the introduction of a new Australian Curriculum that requires students learn about abstract Earth science concepts; the inadequacy of teachers' professional knowledge to address pedagogically these demands; the limitations of teacher education to alleviate pre-service teachers' perceived pedagogical inadequacy in teaching Earth science; and issues of students' durably held alternative conceptions about Earth science phenomena and perceived disengagement with the subject. These challenges call for research that investigates the efficacy of innovative conceptual change pedagogies that promote students' engagement with Earth science and enhance their conceptual understanding.

In response to this need, this study investigated the value of using student-generated stop-motion animation, or 'slowmation', as a conceptual change instructional approach. This study employed a mixed-methods intervention research design, generating both quantitative and qualitative data, in order to investigate three research questions: (1) Does the process of constructing a slowmation have a significant effect on students' conceptual change? (2) How does the process of constructing a slowmation influence students' conceptual change; and (3) Is students' interest, generated by the construction of a slowmation, a significant predictor of conceptual change?

Four classes of Year 9 students participated in this study. Two classes were treated as an intervention group and participated in the construction of a slowmation (*N*=52), while two comparison classes experienced 'teaching as usual' (*N*=43). All students in the intervention and comparison conditions completed a two-tiered multiple-choice test (i.e., the *GeoQuiz*), developed and validated by the researcher, which tested students' alternative Earth science conceptions before and after their participation in the study. A Likert-style survey that gauged students' interest in learning science, the *Student Interest in Learning Science (SILS) Survey*, was also administered to all students before and after the project. Selected students from the intervention condition were audio recorded to

capture their discussions during the construction process, and the same students were interviewed about their learning experience upon completion of the project.

In answer to the first research question, a significant improvement was found in the GeoQuiz scores of students who constructed a slowmation, which indicates that conceptual change occurred. At the same time, a significant improvement was also found for students in the comparison classes. This suggests that creating a slowmation was no more effective in bringing about conceptual change than teaching as usual. In response to the second research question, analysis of the qualitative data in this study found that the construction process afforded ‘teachable moments’ as students recursively checked the accuracy of their representations with their teacher. The construction process also stimulated students’ enjoyment, which they perceived to enhance their learning. Despite these affordances, however, significant pedagogical considerations arose from the use of slowmation as an instructional strategy in a junior secondary school context. These issues appeared to inhibit opportunities for conceptual change to occur. Finally, in answer to the third research question, it was found that students’ interest in learning about science, and geology, was significantly greater if they participated in the construction of a slowmation, compared to teaching as usual. Interest was also found to be a significant predictor of students’ conceptual change.

The findings from this study have important implications for understanding the value of using slowmation construction as a conceptual change strategy in a junior secondary science context. As such, they informed the development of a pedagogical framework, the *Learning with Slowmation* framework, for constructing slowmations in a junior secondary science context. This framework, as well as the significance and implications of the broader findings for improving teaching practice in Earth science education, are presented.

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Statement on the Contribution of Others

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The research reported in this thesis was conducted within the guidelines for research ethics outlines in the National Statement on Ethical Conduct in Human Research (2015). The research design and procedures received ethics clearance from James Cook University's Human Ethics Committee (Approval Number: H5966). The research project was also approved by the Executive Principal at the College where the research was undertaken, in accordance with the Guidelines for Conducting Research on Departmental Sites.

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CHAPTER ONE: INTRODUCTION

1.1 Context and Background

Learning about Earth's physical systems is becoming increasingly important in school science education. Earth science education provides students with the knowledge and skills required to engage with contemporary issues such as dwindling natural resources, climate change, threats to biodiversity, and more frequent and intense natural hazards (Australian Curriculum and Assessment Reporting Authority [ACARA], 2016a; Dawson & Carson, 2013). Despite its importance, Earth science education in Australia, where this research was conducted, appears to be in a state of disarray, amidst issues of historical prejudice against the subject (compared to other science disciplines); mandated attention to Earth science in recent national curriculum changes; teachers questioned pedagogical proficiency in delivering the Earth science curriculum, with its attention to abstract science concepts; concerns around teacher preparedness to address these requirements; and, most importantly for this study, students' disengagement with Earth science, and the durability of their alternative conceptions about Earth science phenomena (Figure 1.1).

In Australia, Earth science (i.e., learning about Earth's physical systems) is mandated from Preparatory to Year 10 in the *Earth and Space Sciences* sub-strand of the *Foundation to Year 10 Australian Curriculum: Science* (ACARA, 2016b). Although science is not yet compulsory in Australia's senior secondary curriculum, students can elect to study a subject called 'Earth and Environmental Science' (ACARA, 2016a). Each state and territory is responsible for implementing its own senior secondary curricula. At present, there are five different versions of Earth science enacted in senior secondary schools. These are: 'Earth and Environmental Science' (Australian Capital Territory; New South Wales; Western Australia); 'Earth Science' (Queensland); 'Geology' (Northern Territory; South Australia); 'Environmental Science' (Victoria); and 'Environmental Science and Society' (Tasmania).

The different Earth science curricula taught in Australian schools presents significant challenges for teachers. In particular, there are concerns that teachers are underprepared to teach students about Earth's physical systems, as they lack content knowledge about geological phenomena (Dawson & Moore, 2011) and the pedagogical content knowledge required to teach such concepts effectively (Lane, 2015). Furthermore, Earth and Environmental Science integrates two conceptually distinct disciplines. It's unlikely that teachers are prepared to teach both, while limited opportunities to access professional development and few innovative resources to support student learning has exacerbated this issue (Dawson & Moore, 2011; Stoltman, Lidstone, & Kidman, 2015).

Earth science has extremely low student enrolments compared to the other senior secondary science subjects; namely, chemistry, physics and biology (Ainley, Kos, & Nicholas, 2008). While this may be due, in part, to inadequate teacher education, research has shown that students find geology concepts difficult, boring and irrelevant to their future careers (Dawson & Carson, 2013). There is also a perception among Australian students and teachers that, due its multidisciplinary nature, Earth science is 'easy' and attracts low ability students (Burg, 2003; Dawson & Carson, 2013). This perception can be attributed partly to the fact that few Australian universities require Earth science as a pre-requisite subject for entry to study their courses.

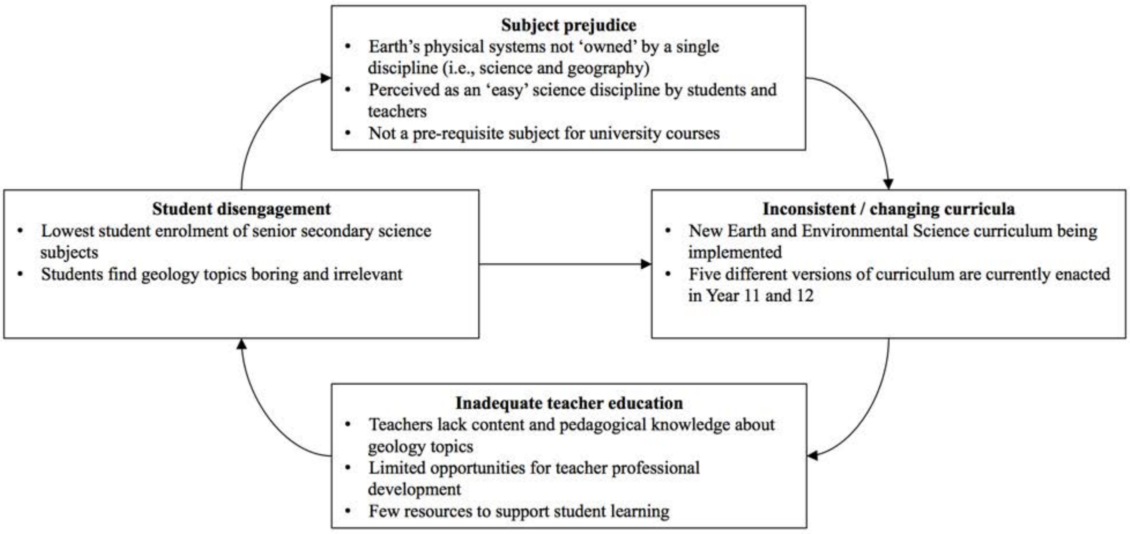

Figure 1.1. A diagrammatic representation of the issues influencing Earth science education in Australia.

There is a distinct need for innovative research projects in the Earth science discipline, such as the one presented in this thesis, that address these concerns and inform curricular design and implementation at the classroom level. Although it is beyond the scope of this thesis to address all of these concerns, it has been suggested that "pedagogies of the science classroom … have a major influence on students' choice of whether or not … science should be part of their future education" (Pike & Dunne, 2011, p. 498). As such, it follows that researchers should develop and evaluate instructional approaches that engage school students in Earth science whilst enhancing their conceptual understanding.

In order to design a research project that achieves this aim, the researcher reflected on his own junior secondary students' learning about Earth science. He noticed that students appeared to have incorrect pre-instructional ideas about Earth science topics, often originating from their frequent misrepresentation in textbooks and popular culture, such as science fiction and children's movies. The researcher was frustrated because students' incorrect ideas persisted after instruction, despite his attempts at facilitating conceptual change. It was obvious that students rote learned content knowledge for assessment purposes and their alternative conceptions remained firmly held and resilient to change. Unsatisfied with the traditional, often behaviourist, instructional approaches already enacted at his school, the researcher identified the need for a constructivist approach to learning in Earth science that took into consideration the ideas that students bring with them to the classroom, and the possibility of using new developments in teaching practice to support student engagement and learning.

Research in science education confirms that students come to science classes with pre-instructional alternative conceptions. These alternative conceptions are often incomplete or incorrect and need to be aligned better with accepted scientific concepts through instruction. While there is much evidence in the literature to suggest that students hold alternative conceptions about Earth science concepts, there appears to be a paucity of intervention studies aimed specifically at correcting these ideas (Cheek, 2010; Francek, 2013; King, 2008; Lelliott & Rollnick, 2010).

A review of conceptual change instructional approaches in the Earth science discipline, elaborated further in Chapter 2, found that intervention studies in this discipline area have both theoretical and methodological shortcomings (Mills, Tomas, & Lewthwaite, 2016). First, there is a lack of research in this discipline that challenges traditional notions of knowledge restructuring by adopting 'multiple perspectives' of conceptual change (Tyson, Venville, Harrison, & Treagust, 1997). In particular, one perspective that remains under-researched considers affective variables as causal mechanisms for change. While factors such as interest, self-efficacy and emotion have been shown to influence students' conceptual change in other science disciplines (e.g., Sinatra & Mason, 2013), research of this nature has not been carried out in Earth science. Second, intervention studies that aim to address students' alternative conceptions about geological phenomena are rare (Cheek, 2010; Francek, 2013; King, 2008; Lelliott & Rollnick, 2010); other Earth science phenomena (especially astronomical phenomena, which were included in the review) have been researched to a much greater extent. Third, there is obvious merit in instructional approaches that require the physical construction and manipulation of multiple representations, through the use of new technologies. In these instances, there are several opportunities for students to consider and revise their alternative conceptions. While this is not an entirely new idea and has been researched in other science disciplines such as chemistry (e.g., Chang, Quintana, & Krajcik, 2010), instructional approaches that emphasise opportunities to construct multiple representations of Earth science phenomena are virtually non-existent.

1.3 Aims and Research Questions

In response to some of the issues canvassed above, this research sought to investigate the value of constructing slowmations as a conceptual change instructional approach in Earth science. A slowmation representation is a student-generated stop-motion animation. During the process of creating a slowmation, students used a variety of representations (e.g., text, diagrams, physical models, narration) to explain the geological processes that occur at tectonic plate boundaries. In this study, each manipulation was photographed with an iPad™ using an application called *MyCreate*™, and the photographs were displayed at two frames per second to create a moving animation.

The study was conducted with Year 9 students (*N*=95) at a Preparatory to Year 12 college in South-East Queensland. Four science classes participated in the research and were randomly assigned to intervention and comparison conditions. While two intervention classes created a slowmation to represent a tectonic plate boundary, two comparison classes experienced 'teaching as usual', in alignment with the College's usual program of instruction. The three research questions that guided the study were:

1. Does the process of constructing a slowmation have a significant effect on students' conceptual change in Earth science?
2. How does the process of constructing a slowmation influence students' conceptual change?
3. Is students' interest, generated by the construction of a slowmation, a significant predictor of their conceptual change?

1.4 Significance

This research responds to the aforementioned theoretical and methodological shortcomings of existing research. The research questions are very different from one another, and each requires unique methods of data generation. Subsequently, the research presented in this thesis is multifaceted and complex, and contributes to multiple fields of educational theory and practice. Specifically, this study extends conceptual change research in the Earth science discipline, particularly of geological phenomena; investigates the interplay between students' interest and conceptual change, thus challenging traditional cognition-only views of knowledge restructuring; and contributes to research that investigates the value of constructing multiple representations of phenomena using slowmation.

This study's findings have the potential to inform best practice in Earth science education in schools and teacher education programs. It is important that research in this field is developed since the Australian Curriculum now mandates that students studying Science in Year 9 are required to learn about Earth science concepts such as continental movement, plate tectonics and geologic activity (i.e., earthquakes and volcanoes). In Queensland, where this study is located, this is embedded within a mandated unit for state schools in the *'Curriculum into the Classroom'* (C2C) unit of work entitled *'Changing Earth'* (Department of Education Training and Employment [DETE], 2014a)[1]. This is not an isolated occurrence of Earth science across the Australian Curriculum, as Queensland students studying Geography in Year 8 also complete a C2C unit entitled *'Landscapes'* (DETE, 2014b), while Year 10 students studying Science complete a C2C unit entitled *'The Universe'* (DETE, 2014c).

It is now undisputed in science education research that cognition-only models of conceptual change are not appropriate given the emergence of constructivism as the major theoretical perspective of learning. Despite emerging efforts to explore how affective variables may bring about conceptual change, this area is still under-researched. In particular, few studies have investigated how interest may bring about conceptual change. Of those that do, there are contradictory findings. While some authors report that students' interest relates positively to conceptual change (Andre & Windschitl, 2003), others argue that highly interested students may be more resistant to change (Dole & Sinatra, 1998). In response to this, the current research aimed to determine the extent to which students' interest generated by constructing a slowmation influences their conceptual change, and will extend existing conceptual change research that adopts an affective perspective.

Existing studies that have investigated the efficacy of slowmation construction as a conceptual change strategy strongly advocate for its use in teacher education courses, and recommend extending its application to school-aged learners. Given that very limited empirical research has explored this possibility, the current study responds to this gap in the literature by investigating how creating a slowmation influences Year 9 science students' conceptual development. More broadly, the research also responds to a lack of "efficient conceptual change instruction strategies" (Treagust & Duit, 2008, p. 35), and

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[1] Queensland schools have been enacting the Australian Curriculum from Preparatory to Year 10 in a range of learning areas since 2012. State schools (and, to some extent, independent and Catholic schools) have been supported by the resource 'C2C', which is a suite of whole-school and classroom curricula and resources. C2C curricula and resources are implemented by schools, and adapted to suit school contexts and individual student's learning needs.

studies that further this research agenda are crucial if the theory-practice gap in relation to conceptual change research is to be narrowed (Treagust & Duit, 2008).

1.5 Thesis Overview

This chapter has reviewed briefly the current state of Earth science education in Australia and established the need for a conceptual change approach to learning in this discipline. It presented the research questions that were investigated and the knowledge gaps that they address. Chapter 2 offers a critical review of the literature that has informed the study. This chapter, in part, systematically reviews conceptual change instructional approaches that have been used in the Earth science discipline over the past 25 years. The research design and procedures, including the methods of data generation and analysis, are presented in Chapter 3. Chapter 4 describes the development and validation of the two instruments employed in the study; namely, a two-tiered multiple-choice test (i.e., the *GeoQuiz*) and a student questionnaire (i.e., the *Student Interest in Learning Science* [*SILS*] *Survey*). The quantitative analysis of the results produced by these instruments is presented in Chapter 5. To provide a more nuanced understanding of these results, Chapter 6 presents two key findings that arose from the qualitative analysis of think-aloud data, captured while students constructed a slowmation, and student interviews. A discussion of the study's overall findings is presented in Chapter 7. This chapter discusses three claims that arose from the analysis of the data and introduces a pedagogical framework, the *Learning With Slowmation (LWS) Framework*, that can be used by teachers to facilitate the effective use of slowmation construction in junior secondary science. Finally, in Chapter 8, concluding remarks and recommendations for further research are presented.

CHAPTER TWO: LITERATURE REVIEW

2.1 Chapter Introduction

This chapter presents the literature that informed the project's research aims and design. It is presented in five main parts. Section 2.2 provides a brief introduction to learning in science and situates the research within a constructivist orientation, which will be argued is most aligned to the requirements of Earth science education given the aforementioned concerns. For this reason, Section 2.3 is a critical review of the conceptual change literature in science education generally. This section details the development of several perspectives of conceptual change and examines the role of affective variables in bringing about conceptual change. Section 2.4 is a systematic review of conceptual change literature specifically relating to Earth Science education. This section reviews conceptual change approaches that have been used previously in Earth science, and the methods that have been used to evaluate the effectiveness of these approaches. Section 2.5 examines research on student-generated animations, including slowmation, and establishes it as a potential conceptual change approach by positioning it within a conceptual change theoretical framework. Finally, in Section 2.6, the chapter concludes with a discussion of the implications of the key findings of the literature review for the current study that delineate it from existing conceptual change research, both in research aim and method.

2.2 Learning in Science

Traditional notions of learning in science are influenced by behaviourist learning theory. The premise of behaviourist instruction, influenced mainly by the work of Skinner (1954), is the idea that learning occurs as a result of reinforcing desired behaviours. This view of learning in science assumed that the learner has no knowledge of a topic before being formally taught, and the learner's mind was viewed as a *tabula rasa* to be 'filled' with science information (Gilbert, Osborne, & Fensham, 1982).

These early views are in stark contrast to the constructivist theories that now inform learning in science. Constructivist approaches recognise the influence of prior experience on how phenomena are perceived and interpreted, emphasising the importance of the learner's existing knowledge in the meanings that they construct (Ausubel, 1968; Driver & Oldham, 1986; Gilbert et al., 1982; Osborne & Freyberg, 1985; Osborne & Wittrock, 1985; Vosniadou & Brewer, 1987). Thus, "the sense made of any event is seen to be dependent not only on the situation itself but also on the individual's … active construction of meaning" (Driver & Oldham, 1986, p. 106).

The modification of an individual's existing conceptual structures has been termed 'conceptual change' (Hewson, 1981; Posner, Strike, Hewson, & Gertzog, 1982). Conceptual change theory, therefore, is concerned with how students' pre-instructional conceptions can be aligned better with accepted scientific concepts. The premise that an individual's existing ideas influence their learning is evident in models of conceptual change that have permeated much of the science education research in the 1980s and 1990s. Significant attention is devoted to reviewing the conceptual change literature in the following section.

2.3 Conceptual Change in Science

Notions of conceptual change have been evident in science education literature for the past three decades. This section will detail the progression of conceptual change since the early 1980s. It will draw on the views of prominent researchers in the field to make assertions about the current state of conceptual change research.

Research in science education has shown that students commonly come to science classes with incomplete or incorrect pre-instructional alternative conceptions that need to be aligned better with accepted scientific concepts. The classical view of conceptual change holds that alternative conceptions can be altered by or replaced with scientific concepts (Hewson, 1981; Posner et al., 1982). There are three conditions that must be met for conceptual change to occur: intelligibility, plausibility and fruitfulness (Posner et al., 1982). A concept is intelligible once understood by the student; plausible if it aligns with the student's existing conceptions, and is thus believable; and fruitful if it is useful to the student.

Proponents of the classical conceptual change model believe that it is possible to determine the degree to which a student has met the conditions required for conceptual change to occur. Treagust and Duit (2008) explore further how intelligibility, plausibility and fruitfulness may manifest. Their research has shown that intelligibility often manifests as a linguistic or symbolic representation of a given concept. For instance, a concept is intelligible if a student can use an analogy, metaphor or diagram to represent the concept, or they can provide a real-world example of the concept. If a student is able to link the concept with observations or data from science lessons, or their individual past experiences, then it can be assumed that the concept is believable, or plausible, to the student. Finally, if a concept has wide applicability and the potential to solve problems (particularly problems that arise from competing conceptions) then it is viewed as being fruitful to the student.

It is well established that existing conceptions are often resistant to change, and as such, conceptual change approaches commonly aim to cause ‘conceptual conflict’ (Hewson, 1981; Posner et al., 1982). This occurs when a student becomes aware that a scientific conception does not align with his/her existing conception. Often, conceptual conflict is a result of contradictory evidence, anomalous data or a discrepant event. Posner et al. (1982) broadly term these examples ‘anomalies’; that is, unsuccessful attempts to integrate a new conception within existing conceptual frameworks. Conceptual conflict is often viewed as a fourth condition necessary for conceptual change to occur (Hewson, 1981; Posner et al., 1982).

Although the premise of conceptual change is simple, the interaction between existing and new conceptions is complex. The outcome of the interaction is dependent on a student’s ‘conceptual ecology’, a term that Posner et al. (1982) borrowed from earlier work in cognitive science (Toulmin, 1972). A student’s conceptual ecology refers to the “conceptual framework by which he or she makes sense of the world” (Hewson, 1981, p. 392). It includes an individual’s epistemological commitments and metaphysical beliefs about science (Posner et al., 1982), and has evolved over the past three decades to include a range of affective factors (Pintrich, Marx, & Boyle, 1993).

The ‘status’ afforded to a new conception depends on its relationship with existing cognitive frameworks, and therefore, the degree to which the student finds the new conception intelligible, plausible and fruitful (Hewson, 1981). A student may: (1) accept the new concept and replace existing conceptions; (2) accept the new concept alongside existing conceptions; (3) reject the new concept; or (4) compartmentalise the new concept so that it does not interact with existing conceptions (i.e., rote learn) (Hewson, 1981; Posner et al., 1982). If a new conception is preferred (i.e., has a higher conceptual status) then it may be accepted and replace an existing conception. This has been termed ‘conceptual exchange’ (Hewson, 1981) or ‘accommodation’ (Posner et al., 1982). If neither conception has a higher status, then the new conception may be accepted alongside existing conceptions, and is known as ‘conceptual capture’ (Hewson, 1981) or ‘assimilation’ (Posner et al., 1982). This may involve the addition of a new conception and/or reorganisation of existing conceptions. It has been suggested that this type of conceptual change is most common (Duit & Treagust, 1998). Often, features of the scientific concept will merge with existing conceptions, resulting in ‘peripheral’ conceptual change (Chinn & Brewer, 1993). This occurs because the scientific conception is not a source of cognitive conflict. Rather, it is able to be reconciled with the student’s existing conceptions, and is “seen in the context of his or her present knowledge and understanding” (Hewson, 1981, p. 368). If the new conception is not accepted, no conceptual change will occur. This may occur if the learner has a strong commitment to their existing conception (Hewson, 1981). Finally, the new conception may have no interaction with existing conceptions. This has been described as ‘cognitive segregation’, where “students create a compartment for scientific knowledge from which it can be retrieved on special occasions, such as a school exam, but in everyday life it has no affect” (Cobern, 1996, p. 588). This occurs if a new concept is rote learnt.

Whether conceptual change occurs suddenly or develops slowly over time is a question that has received much attention in the literature. In their classical conceptual change model, Posner et al. (1982) drew from Thomas Kuhn’s work on ‘scientific revolutions’ and Piaget’s ideas of assimilation and accommodation (Treagust & Duit, 2008). Conceptual changes were traditionally viewed as radical and abrupt. Since then, it has been suggested that conceptual change lies on a continuum from ‘revolutionary’ to ‘evolutionary’. The nature of the conceptual change that occurs is dependent on factors such as the concept being learned and the instructional approach (Treagust & Duit, 2008). A developmental perspective also exists that suggests young children’s ideas are often based on their everyday experience, and are fundamentally different from those of adults or scientists. Therefore, conceptual change is viewed as a “*gradual process* during which initial conceptual structures … are *continuously enriched and restructured*” (Vosniadou & Ioannides, 1998, p. 1221; emphasis added). There is a general consensus now that conceptual change occurs gradually over time, in alignment with this view. As such, this is the view of conceptual change that has informed the current study.

At this point it is important to acknowledge and define relevant terminology in the field of conceptual change, and clarify the terms that will be used henceforth in the current study. The term ‘conception’ will be used to describe an “individual’s idiosyncratic mental representations” (Duit & Treagust, 1995, p. 47) of a scientific phenomenon. Conceptions are “dynamic, situated, and constantly changing representations that adapt to contextual variables and/or to the learners’ developing knowledge” (Vosniadou, 2008, p. 279). In contrast, the term ‘concept’ will refer to “firmly defined or widely accepted” conceptions (Duit & Treagust, 1995, p. 47). The incorrect or incomplete pre-instructional conceptions that students bring with them to science classes will be referred to as ‘alternative conceptions’, to emphasise the difference between students’ idiosyncratic conceptions and more widely accepted scientific concepts. Finally, both ‘conceptual change’ and ‘conceptual development’ have been used purposefully throughout the thesis, to differentiate between ‘strong’ and ‘weak’ conceptual change respectively. In other words, the term ‘conceptual change’ has been used to describe the complete replacement or modification of an existing conception, whereas ‘conceptual development’ has been used to describe the addition of scientific ‘elements’ to an existing conception. It is to be noted that these definitions are not consistent with notions of classical conceptual change as described above, but rather, they recognise that there are multiple perspectives about the nature of misconceived knowledge and what constitutes conceptual change.

2.3.1 The development of multiple perspectives

There are multiple perspectives concerning the nature of conceptual change that give rise to different conceptual change models. One variation of the classical conceptual change model suggests that alternative conceptions arise if students assign concepts to incorrect ontological categories (Chi, Slotta, & De Leeuw, 1994). From this perspective, conceptual change occurs when students change the way they perceive the nature of a conception. Another variation considers the role of affective factors, such as motivation, interest and self-efficacy, as variables that bring about conceptual change (Pintrich et al., 1993). Finally, some authors have advocated for a multidimensional model that views conceptual change from epistemological (classical), ontological and affective perspectives (Treagust & Duit, 2008; Tyson et al., 1997).

Notions of conceptual change have developed over the last three decades in response to much discussion in the field. Perhaps the most well known critique of the conceptual change model is presented by Cobern (1996). His commentary presents two major assumptions inherent to the model. First, the conceptual change model assumes that scientific conceptions are superior to alternative conceptions (Cobern, 1996). Second, the model assumes that students come to science classes with a scientifically compatible worldview (Cobern, 1996). This is problematic given that science conceptions may not always align with a student's worldview, and therefore, their alternative conception will persist, irrespective of whether the scientific concept is comprehended by the learner. Cobern (1996) argues that "knowing is a metaphysical process by which one comes to apprehend, that is to accept as true or valid, the concept one has comprehended. Of critical importance is the fact that comprehension does not necessitate apprehension" (Cobern, 1996, p. 13). Others have acknowledged this view and have labeled the ideas that students bring with them to science classes as sensible and useful (e.g., Osborne & Wittrock, 1985).

A second argument that surfaced shortly after the publication of Posner et al.'s (1982) work concerns the role of affective factors in conceptual change. In the classical conceptual change model, the authors describe learning as a "rational activity" (Posner et al., 1982, p. 212) where judgments are made about ideas "on the basis of evidence" (Strike & Posner, 1982, p. 232). It has been suggested that this "cognition-only model" (Pintrich, et al., 1993, p. 167) is an over-rationalised view of learning that fails to consider the role of factors such as motivation, interest, self-efficacy, feelings and emotions as "conceptual supports for new knowledge" (Tytler & Prain, 2010, p. 2058). It is even suggested that 'non-rational' factors such as feelings "are integral parts of what learning is and not simply … affective antecedents upon which learning depends" (West & Pines, 1983, p. 38). In a revision of their conceptual change model a decade after its publication, Strike and Posner (1992) acknowledged that "a wider range of factors need to be taken into account in attempting to describe a learner's conceptual ecology" (p. 162). Despite the argument for further research into the interplay between affect and conceptual change, there remains little research that explores this.

Some studies, for example, those pioneered by Chi and colleagues (1994), have viewed conceptual change from an ontological perspective. They argue that "although Posner's theory is widely accepted by science educators and easy to comprehend and apply to learning activities … it does not delineate what the nature of a scientific concept is, which causes difficulty in learning the concept" (Chi, Chou, & Liu, 2002, p. 689). Their perspective of conceptual change is based upon three principles. First, conceptions belong to one of three primary ontological categories, or 'trees' (namely matter, processes and mental states); second, most scientific principles belong to a process category; and third, alternative conceptions may arise if students incorrectly assign concepts to these categories. They have argued that many science concepts are inaccurately conceptualised as matter rather than processes, and alternative conceptions arise as a result. From this perspective, conceptual change is how the student perceives the nature of a conception, and occurs when students re-assign an ontological category to a conception (called 'tree swapping'). This suggests that conceptual change can occur if a student changes the way he/she views a concept.

While the classical conceptual change model and many conceptual change studies over the last three decades view conceptual change from an epistemological perspective, ‘affective conceptual change’ has been given greater attention in response to the aforementioned arguments. The notion of affective conceptual change perhaps originated from research conducted by Pintrich et al. (1993), although West and Pines (1983) suggested that there is a relationship between affective factors and cognition much earlier. Early studies in this area (e.g., Venville & Treagust, 1998) sought evidence of affective conceptual change in students’ comments at interview, and only recently, more objective, quantitative attempts to link affect and cognition have surfaced (e.g., Cordova, Sinatra, Jones, Taasoobshirazi, & Lombardi, 2014; Linnenbrink-Garcia, Pugh, Koskey, & Stewart, 2012). Section 2.3.2 gives significant attention to the role of affective variables including achievement goals, epistemic motivations and beliefs, interest and self-efficacy in bringing about conceptual change.

In the mid to late 1990s, some authors began to adopt a multidimensional perspective of conceptual change (Venville & Treagust, 1998; Tyson et al., 1997). This approach views conceptual change from epistemological, ontological and affective perspectives:

> The ontological lens of the multidimensional framework of conceptual change examines the way a student perceives the nature of the thing being studied; that is, the student is looking “out” at the world. The epistemological lens examines how the student perceives his or his own knowledge about the thing being studied; that is, the student is looking “in” at their own knowledge. The social/affective lens examines the social/affective conditions necessary for conceptual change to occur. (Tyson et al., 1997, p. 398)

A multidimensional perspective of conceptual change has been used in a number of studies, including an exploration of Year 10 students’ (N=79) conceptions of genes during a 10-week genetics course (Venville & Treagust, 1998). The authors found that each of the three perspectives of conceptual change had explanatory value and offered different theoretical perspectives to make judgments about students’ conceptual development.

Finally, since conceptual change models are firmly situated within constructivist orientations, where students construct knowledge for themselves, the notion of ‘intentional conceptual change’ has arisen (Sinatra & Pintrich, 2003). From this perspective, “learners do not necessarily plan to modify their knowledge in a particular way” (Sinatra & Taasoobshirazi, 2011, p. 209). While a student may be intentionally engaged in knowledge construction, they are not necessarily engaged in a deliberate process of knowledge *reconstruction*. Intentional conceptual change is therefore dependent on a variety of factors that may be considered self-regulatory, including cognitive, metacognitive and motivational processes (Sinatra & Pintrich, 2003). Although the notion of intentional conceptual change is probably not typical, instructional approaches based on this perspective have the potential to bring about conceptual change in instances where alternative conceptions about science are firmly held by students:

> The intent to change and the self-regulation of the change process is critical in science because students come to the science learning situation with deeply held knowledge and beliefs that conflict with scientific understanding. To overcome such strongly held misconceptions, self-regulated, intentional conceptual change may provide the leverage needed to overcome these barriers. (Sinatra & Taasoobshirazi, 2011, p. 210)

Recently, notions of classical conceptual change have been challenged throughout the conceptual change literature. Adopting a multidimensional perspective of conceptual change that includes combinations of classical, ontological and affective perspectives has been suggested as the most current approach to furthering research in the field (Treagust & Duit, 2008). The following section pays particular attention to affective variables that influence students’ conceptual development by summarising the existing research literature.

2.3.2 The ‘warming’ trend

Perhaps the most significant development in the field of conceptual change research is the ‘warming trend’ that describes the move away from cognition-only models of conceptual change (Sinatra, 2005). As identified in the previous section, early studies in this area sought evidence of affective conceptual change in students' comments at interview, and only recently, more objective, quantitative attempts to link affect and cognition have surfaced. The research that is emerging shows that certain 'learner characteristics' seem to influence the occurrence of conceptual change (Sinatra & Mason, 2013). These include achievement goals (Taasoobshirazi & Sinatra, 2011); epistemic motivations and beliefs (Qian & Pan, 2002); interest (both individual and situational interest) (Andre & Windschitl, 2003; Mason, Gava, & Boldrin, 2008; Murphy & Alexander, 2004; Venville & Treagust, 1998); and self-efficacy (including students' commitment to and efficacy about alternative conceptions) (Linnenbrink-Garcia et al., 2012). It also appears that a certain combination of affective characteristics might predict conceptual change (Cordova et al., 2014; Linnenbrink-Garcia et al., 2012).

Increased attention has been paid to understanding the influence of these characteristics in bringing about conceptual change. A review of studies that examine the relationship between affective factors and conceptual change conducted by Sinatra and Mason (2013) identifies research on the following affective variables: achievement goals; epistemic motivations and beliefs; interest; and self-efficacy. These will now be briefly reviewed, in turn.

Achievement goals: Both mastery and performance achievement goals have been found to promote conceptual change (Linnenbrink & Pintrich, 2002; Qian & Pan, 2002; Taasoobshirazi & Sinatra, 2011).

Epistemic motivations and beliefs: An 'avoiding closure' motivation, where students seek new information, question current ideas and solve discrepancies and problems, has been positively linked to conceptual change (Kruglanski & Webster, 1996). Also, the belief that knowledge is changing rather than static has been conducive to conceptual change (Qian & Alvermann, 1995).

Interest (topic interest and situational interest): Research regarding the impact of interest on students' conceptual change has yielded mixed results, with some studies showing a positive link, and others showing a negative relationship (Andre & Windschitl, 2003; Venville & Treagust, 1998).

Self-efficacy (students' confidence in their capability and their commitment to alternative conceptions): Studies that investigate students' self-efficacy have also produced mixed results. Some studies report that students' self-efficacy creates confidence in their capability to learn through changing their ideas (Cordova et al., 2011), while others report that students' self-efficacy enhances their commitment to their alternative conceptions (Linnenbrink-Garcia et al., 2012).

Recent studies have examined how combinations of affective variables might predict conceptual change. Cordova et al. (2014) point out that although several affective variables are hypothesised to play a role in bringing about conceptual change, research demonstrates that when these variables are considered in isolation, they are not successful in doing so. When they are considered alongside other affective variables, however, certain combinations have brought about conceptual change. For instance, when self-efficacy, interest and prior knowledge are considered alone, they have been found to have no influence on conceptual change, but when considered together, they support conceptual change (e.g., Linnenbrink-Garcia et al., 2012).

The Cognitive Reconstruction of Knowledge Model (CRKM) describes the interaction between a learner's characteristics and a new concept (Dole & Sinatra, 1998). The model pays particular attention to the influence of background knowledge (including the strength and coherence of, and commitment to, existing conceptions) and motivational factors on conceptual change. The premise of the model is that students will engage with a concept at a certain level (from high engagement to low engagement) based on the interaction between background knowledge, motivational factors and cognitive processes (i.e., whether the concept meets the traditional conditions considered necessary for conceptual change to occur). This, in turn, determines the conceptual change that takes place: none, weak, strong or long lasting.

2.4 The Earth Science Context: A Systematic Review of Conceptual Change Instructional Approaches

This section presents a systematic literature review of conceptual change instructional approaches employed in the Earth science discipline over the past 25 years. The findings of this review are also published in Mills et al. (2016). It is to be noted that instructional approaches for teaching astronomy have been included in this section of the review. This was a methodological decision made by the researcher in response to finding very few intervention studies specific to geology topics. The decision to widen the scope of the review is warranted, given that astronomical phenomena operate on spatial and temporal scales that are difficult to directly observe, and research indicates that students have widespread alterative conceptions about such phenomena (see Lelliott & Rollnick, 2010). These challenges are common also to geological concepts. Furthermore, it would be remiss not to review instructional approaches from such an intimately related discipline wherein conceptual change research is more established, and use the findings to further inform and justify the current study.

In this section of the literature review, procedures for reviewing the literature according to Randolf (2009) were adopted. As the process of conducting secondary research mirrors the process of conducting primary research, the tasks to conduct a systematic literature review include: (1) problem formation; (2) data collection; (3) data evaluation; (4) analysis; and (5) interpretation (Randolf, 2009). These tasks were operationalised as outlined below.

2.4.1 Problem formation

The first task in problem formation is to develop questions that will guide the literature review. In this review, the two research foci are instructional interventions and methods of conceptual change literature within the Earth and space science discipline. It was the researcher’s aim to integrate findings from multiple approaches and contexts. As such, the following questions were developed to guide this section of the literature review:

1. What are the general characteristics of the literature?

2. What conceptual change instructional approaches have been used in an Earth and space science education context?
3. What methods were used to evaluate the effectiveness of these approaches?
4. What are the recommendations for future research synthesised from the existing literature?

For the purposes of this review, peer-reviewed empirical studies that met the following two criteria were included: (1) quantitative and/or qualitative research methods were employed; and (2) data were generated to determine the effectiveness of a conceptual change instructional approach used in the Earth and space science discipline. The researcher excluded research that simply identified students' alternative Earth and space science conceptions, or did not analyse learning from a conceptual change perspective.

2.4.2 Data collection

The studies included in this review were compiled from four sources: (1) a search of the *Education Resources Information Centre* (ERIC) and *PsychInfo* databases for studies published in 1980 onwards; (2) a manual search of recent issues of science education, educational psychology, and cognitive science journals for studies published in 2010 onwards (a shorter time span was chosen due to the time intense nature of manually searching journals); (3) the reference lists of studies identified as relevant; and (4) the reference lists of three existing literature reviews.

The researcher began with a search of the two academic databases. The following search terms were used: ("Earth science*" OR Geoscience* OR Geolog* OR Astronom*) AND ("conceptual change*" OR "conceptual development*" OR misconcept* OR "alternative framework*" OR "naïve idea*"). As much research now considers the impact of affective variables on students' conceptual change, follow-up searches using the above keywords in addition to (affect* OR emotion* OR interest* OR efficacy) were conducted. The number and specificity of the search terms was refined to ensure that the search results would be a robust representation of the existing research. As well, recent issues of particularly relevant journals were searched manually throughout the preparation of the review to ensure data collection was thorough, namely the *International Journal of Science Education*, the *Journal of Research in Science Teaching*, the *Journal of Science Teacher Education*, *Learning and Instruction*, *Research in Science Education*, *Science Education*, *Studies in Science Education*, *Cognitive Psychology*, *Contemporary Educational Psychology*, *Educational Psychologist*, *Educational Psychology Review*, the *Journal of Educational Psychology*, and the *Journal of Learning Sciences*. Two discipline-specific science education journals were searched manually; the *Journal of Geoscience Education* and *Astronomy Education Review.*

Finally, the reference lists of relevant studies were analysed to identify any further relevant studies, and so on, until a point of saturation was reached where the researcher was certain that no more relevant studies could be obtained from this process. Particular attention was given to four existing literature reviews of Earth science or astronomy education, conducted by Cheek (2010), Francek (2013), King (2008) and Lelliott and Rollnick (2010).

2.4.3 Data evaluation

The overall approach to data collection and evaluation is shown in Figure 2.2. The researcher identified potentially relevant studies from hundreds of search results by first reading their title and abstract. Following this, many of the studies were read in full to determine their relevance. Information was extracted from 52 studies only. The remaining studies were excluded from the review for two main reasons. First, these studies did not analyse learning from a conceptual change perspective. Instead, they presented interventions that increased students' conceptual knowledge, but were not specifically designed to address students' alternative conceptions or measure conceptual change (e.g., Gobert & Clement, 1999). Second, these studies were theoretical discussions, or simply identified students' alternative conceptions and did not evaluate an intervention designed to change them (e.g., Blown & Bryce, 2006; Vosniadou & Brewer, 1992).

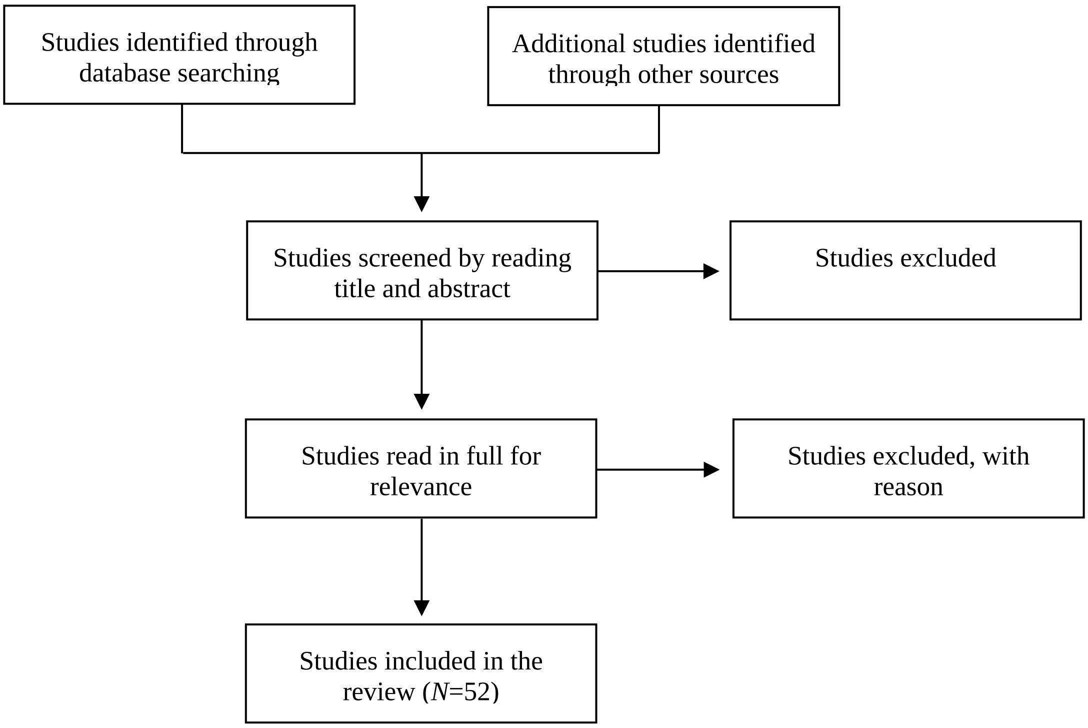

Figure 2.1. A summary of the process of selecting studies to include in this review.

Information extracted from the relevant studies was organised in an electronic database. This included information about each study's author and date of publication; journal of publication; geographical location; research design; theoretical view of conceptual change adopted in the study; setting and participants; methods of data generation and analysis; findings; data that support the findings; limitations of the study; and recommendations for further research. The researcher looked for commonalities among instructional approaches to identify themes and gaps in the existing literature.

2.4.4 Analysis

Studies that investigated conceptual change instructional approaches in the Earth and space sciences have increased over the past 25 years. The majority of instructional interventions over this time have moved from the natural observation of phenomena and the use of physical models, to the use of computer simulations, as technological advances and access to technology has increased. The most effective instructional approaches appear to be those where students physically constructed multiple representations of the phenomena. Although the development of instructional approaches has progressed, there have been limited theoretical and methodological progressions during this transition. This is reflected in four assertions, evidenced by the findings of this review, as follows:

1. Astronomical phenomena have received greater attention in the literature than geological phenomena;
2. Most studies have viewed conceptual change from a cognitive perspective only;
3. Data about conceptual change is generated pre- and post-intervention only; and
4. The interventions reviewed present limited opportunities to involve students in the physical construction of multiple representations.

The findings that support each of these assertions are presented below.

2.4.4.1 General characteristics of the research

The following section presents a summary of the general characteristics of the studies included in this section of the review.

Publisher, date, and location of research. Most of the studies were published in leading science education journals such as the *Journal of Research in Science Teaching*, rather than discipline-specific journals such as the *Journal of Geoscience Education* or *Astronomy Education Review*. Even fewer studies were published in educational psychology journals. The number of intervention studies has increased over the past 25 years. Of the 52 studies included in this review, most were published in the previous decade. Most of the research was conducted in the United States. Research has also been carried out to a lesser extent in Australia, Canada, Cyprus, Finland, Greece, Israel, Italy, Portugal, New Zealand, Taiwan, Turkey and the United Kingdom.

Earth and space science topics. Of all the studies included in the review, the majority reported on an instructional approach designed to facilitate participants' accurate conceptions of astronomical phenomena (*N*=44). Fewer investigated instructional approaches designed to facilitate participants' accurate conceptions of geological phenomena or other Earth science related phenomena such as climate change science

(*N*=8). The most widely researched astronomical phenomenon was the Earth-moon-sun system, including the causes of moon phases and seasons. Other astronomical phenomena researched are participants' conceptions of Earth; the alternation of day and night; the solar system; planetary motion; stars and the sun; light; galaxies; astronomical size and scale; and tides.

Participants. A large proportion of studies were conducted with primary and secondary school students. Some studies were conducted with undergraduate students or pre-service teachers. Very few studies evaluated interventions targeting teachers' alternative conceptions. All of the studies that did so targeted primary school teachers; no studies were aimed at facilitating secondary school teachers' scientific conceptions.

Research design. The majority of studies were small-scale research projects conducted with small groups of students, such as intact classes of elementary school students. Most adopted some sort of single case study research design. As such, the research was mostly exploratory and interpretive in nature. A smaller number of studies were quasi-experimental and aimed to compare intervention and comparison groups.

Theoretical perspective of conceptual change. Almost all of the research conducted viewed conceptual change from a cognitive perspective. Only two studies adopted an affective perspective (Broughton, Sinatra, & Nussbaum, 2013; Cordova et al., 2014). In these studies, the researchers aimed to determine the influence of affective variables on participants' conceptual change. No studies considered how an intervention impacted students' perception of a given concept (i.e., ontological conceptual change).

2.4.4.2 Conceptual change instructional approaches and methods employed to evaluate their effectiveness

The reviewed studies employed several conceptual change approaches to align better the participants' alternative conceptions of astronomical or geological phenomena with accepted scientific concepts. These included simulations, natural observation, refutational text, physical models, analogy, cognitive conflict, student-generated animation and other specific teaching and learning sequences (Table 2.1). In this section, each instructional approach and its effectiveness are reviewed, in turn.

Simulations. Simulations present the most frequently researched instructional approach for bringing about conceptual change. Ten studies investigated the effectiveness of simulations in facilitating participants' accurate conceptions of astronomical phenomena. It is apparent that technological advances and access to technology are allowing researchers (particularly in the last decade) to address the abstract nature of the Earth-moon-sun system and related astronomical phenomena. The research focused on three main simulations: *Starry Night*™ (Bell & Trundle, 2008; Binns, Bell, & Smetana, 2010; Hobson, Trundle, & Saçkes, 2010; Trundle & Bell, 2010), *Virtual Solar System*™ (Gazit, Yair, & Chen, 2005; Keating, Barnett, Barab, & Hay, 2002) and *CosmoWorld*™ (Bakas & Mikropoulos, 2003). These simulations are interactive, allowing for students' direct manipulation of the phenomena under study. While *Starry Night*™ offers a two-dimensional representation of the night sky, *Virtual Solar System*™ and *CosmoWorld*™ offer both three-dimensional representations of the Earth-moon-sun system. One other general modeling program was used (Küçüközer, 2008; Küçüközer, Korkusuz, Küçüközer, & Yürümezoglu, 2009). The majority of this research followed an inquiry-oriented teaching and learning sequence, whereby students: (1) gathered, recorded and shared data about the moon; (2) analysed their data and looked for patterns; and (3) modelled the cause of moon phases (e.g., Bell & Trundle, 2008).

Data were generated pre- and post-intervention and were analysed from a cognitive perspective. Data generation was typically qualitative, as pre- and post-interviews were by far the most common method employed. At interview, students demonstrated their conceptual understanding by completing drawing or modeling tasks. Participants' pre- and post-instructional conceptions were generally coded using a constant-comparative approach. Participants' pre- and post-instructional conceptions were coded using a framework that categorised their ideas on a continuum that included 'no conception', 'incomplete or alternative conceptions', and 'scientific conceptions'. In most cases, this was quantified by assigning a score to the nature of students' conceptions, allowing a per cent increase from pre- to post-instruction to be calculated. Gazit and colleagues (2005) employed an atypical approach by video-recording participants during instruction to capture students' interactions with the simulation.

The studies reviewed reported that there was typically an increase in the number of students who held more scientific conceptions of phenomena post-instruction. It is likely that simulations, being a simplified version of reality, provided access to phenomena that were otherwise unobservable. In the case of *Virtual Solar System*™, this may be due to the three-dimensional representation supporting students' ability to visualise abstract concepts from multiple viewpoints (Keating, Barnett, Barab, & Hay, 2002). This particular simulation, which is especially interactive, is deemed beneficial because of its descriptive and predictive ability; that is, it not only helps explain the Earth-moon-sun system, but through interaction and manipulation, it also helps to explain what might be expected when variables are changed (e.g., the time Earth takes to orbit the sun). One study found that the use of a simulation reinforced students' alternative conceptions (Gazit et al., 2005). The authors suggest a few reasons for this, including that students may have misinterpreted features of the simulation (e.g., the graphics) or experienced difficulty comprehending the multiple viewpoints (i.e., not having a fixed point of reference to view phenomena). Two studies had conflicting findings about the effectiveness of using *Starry Night*™ over natural moon observations (Binns et al., 2010; Trundle & Bell, 2010).

Table 2.1
A summary of the conceptual change instructional approaches and studies included in this section of the review (N=52)

Instructional approach	**Number of studies**	**References**
Simulations	10	Bakas and Mikropoulos (2003) Bell and Trundle (2008) Binns, Bell, and Smetana (2010) Gazit, Yair, and Chen (2005) Hobson, Trundle, and Saçkes (2010) Keating, Barnett, Barab, and Hay (2002) Küçüközer (2008) Küçüközer, Korkusuz, Küçüközer, and Yürümezoglu (2009) Schneps, Ruel, Sonnert, Dassault, Griffin, and Sadler (2014) Trundle and Bell (2010)
Natural observation	8	Lee, Lester, Ma, Lambert, and Jean-Baptiste (2007) Trundle, Atwood, and Christopher (2002) Trundle, Atwood, and Christopher (2006) Trundle, Atwood, and Christopher (2007a) Trundle, Atwood, and Christopher (2007b) Trundle, Atwood, Christopher, and Saçkes (2010) Ucar and Trundle (2011) Ucar, Trundle, and Krissek (2011)
Refutational text	4	Broughton, Sinatra, and Nussbaum (2013) Broughton, Sinatra, and Reynolds (2010) Cordova, Sinatra, Jones, Taasoobshirazi, and Lombardi (2014) McCuin, Hayhoe, and Hayhoe (2014)
Physical models	3	Ogan-Bekiroglu (2007) Shen and Confrey (2007) Steer, Knight, Owens, and McConnell (2005)
Analogy	2	Blake (2001) Blake (2004)
Cognitive conflict	1	Tsai and Chang (2005)
Student-generated animation	1	Nielsen and Hoban (2015)

Other specific teaching and learning sequences	23	Barnett and Morran (2002) Bezzi (1996) Bulunuz and Jarrett (2010) Celikten, Ipekciouglu, Ertepinar, and Geban (2012) Chang and Barufaldi (1999) Chastenay (2016) Diakidoy and Kendeou (2001) Hayes, Goodhew, Heit, and Gillan (2003) Hsu (2008) Kali, Orion, and Eylon (2003) Lombardi, Sinatra, and Nussbaum (2013) Marques and Thompson (1997) Martinez, Bannan, and Kitsantas (2012) Nussbaum and Sharoni-Dagan (1983) Rebich and Gautier (2005) Salierno, Edelson, and Sherin (2005) Sharp and Sharp (2007) Sneider and Ohadi (1998) Stover and Saunders (2000) Taylor, Barker, and Jones (2003) Trumper (2006) Viiri and Saari (2004) Zeilik, Schau, and Mattern (1999)

One methodological limitation associated with simulations was evident in most of the studies. In the many instances where simulations were embedded within a broader teaching and learning sequence, the single case study research design did not delineate the impact of individual instructional activities on the findings (e.g., Bell & Trundle, 2008). Therefore, any conceptual gains were not attributed to the use of the simulation alone, but rather, to the broader instructional approach. Opportunities for further research concern the optimal use of simulations, such as determining the minimum number of *Starry Night*™ moon observations needed for conceptual change to occur (Bell & Trundle, 2008).

Natural observation. The eight studies in this category employed an intervention whereby participants observed astronomical phenomena directly or used second hand data. An inquiry-oriented instructional sequence similar to the one employed by Bell and Trundle (2008) was adopted in these studies (see *Simulations*). Two studies used this instructional sequence to learn about tides by accessing tidal data online (Ucar & Trundle, 2011; Ucar, Trundle, & Krissek, 2011). One of these studies compared this inquiry-based approach with traditional instruction that included lectures and group discussions (Ucar & Trundle, 2011). No studies targeted participants' alternative conceptions about geological phenomena, perhaps due to the fact that many geological processes cannot be directly observed, or occur too slowly to permit direct observation.

Data generation was almost exclusively qualitative, relying mostly on structured interviews with participants. During interviews, participants generally completed drawing or modelling tasks. Two studies relied on students' diagrams only, as they investigated the effect of the instruction on students' ability to draw the moon's phases (Trundle, Atwood, & Christopher, 2006; Trundle, Atwood, & Christopher, 2007a). One study adopted a mixed methods approach, and relied on qualitative and quantitative data to determine the effectiveness of the intervention (Ucar et al., 2011). Structured interviews and a multiple-choice test were the primary sources of data in this study. In all of the studies, data collection occurred exclusively pre- and post-intervention. No studies collected data throughout the intervention, thus preventing any insight into the nature/process of conceptual change. Additionally, this meant that there was no indication of how social interactions may have influenced students' conceptual change, despite the fact that group work was an important component of all of the instructional approaches. One study was unique in that the authors conducted interviews six months after the intervention to determine its effectiveness (Trundle, Atwood, & Christopher, 2007b). Many studies claimed to have sourced data from classroom observations, document analysis, and participants' journals; however, these data were rarely analysed and used as evidence to support the findings of the study (e.g. Trundle et al., 2002; Ucar et al., 2011).

Data analysis in these studies was consistent with the constant comparison approach described in *Simulations*. A paired samples *t*-test was used in the one study that employed a multiple-choice test instrument to measure conceptual change (Ucar et al., 2011). After instruction, most students in all studies showed evidence of holding more accurate scientific conceptions and fewer alternative conceptions. Participants in two studies were more likely to be able to draw a scientific diagram of the moon's phases as a result of the intervention (Trundle et al., 2006; Trundle et al., 2007b). In the study that interviewed participants six months after the intervention, most participants had retained scientific conceptions of moon phases, however, some resorted back to their alternative conceptions (Trundle et al., 2007a). It seems that the participants' direct experience with the phenomena (i.e., conducting natural moon observations or accessing real tidal data) was a crucial aspect of the success of these instructional approaches. Also, as participants worked in groups in all of the studies, the "interpretive, sense-making discussions" (Trundle et al., 2002, p. 653) between individuals may have also been important (although no evidence supports this claim). In the studies where participants analysed tidal data, the fact that pre-service teachers were able to access data over a long period of time and from a range of geographical locations was considered a critical aspect of the instruction (Ucar et al., 2011). A possible explanation for students who did not have accurate scientific conceptions post-intervention, suggested in one study, was that these individuals were not metacognitively aware of the inconsistencies between their alternative conceptions and the scientific conception presented during instruction (Trundle et al., 2007a). Another possibility is that participants' alternative conceptions were reinforced during the physical modelling of phenomena (a part of the broader instructional sequence) due to limitations of the model used (Trundle et al., 2002).

Although the use of natural observation as an instructional strategy holds obvious merit, a variety of directions for future research were suggested. One such direction is that research be conducted with school-aged students (Ucar et al., 2011). To date, research has tended to investigate the effectiveness of this type of instructional approach on pre-service teachers only. Only three studies have extended research to school-aged students (Lee, Lester, Ma, Lambert, & Jean-Baptiste, 2007; Trundle at al., 2007b; Trundle, Atwood, Christopher, & Saçkes, 2010). It has also been suggested that research on a conceptual change intervention wherein participants metacognitively compare their pre- and post-instructional ideas would be particularly insightful (Trundle et al., 2007a). Finally, Ucar et al. (2011) advise that any research that addresses pre-service teachers' alternative conceptions about tides would be beneficial due to the alarming number of non-scientific ideas held by soon-to-be teachers on this topic.

Refutational text. Four studies employed refutational text to bring about conceptual change (Broughton et al., 2013; Broughton, Sinatra, & Reynolds, 2010; Cordova et al., 2014; McCuin, Hayhoe, & Hayhoe, 2014). Of particular interest is Broughton and colleagues' (2013) approach to determine if a refutational text about Pluto's re-classification as a dwarf planet would change students' understanding of the definition of a planet. The text was constructed from a range of magazine articles to explain the changing nature of science, the role of evidence in making scientific decisions, and the history of Pluto's classification as a planet. Students' knowledge about the planets and the reclassification of Pluto were assessed using an open-ended questionnaire. It was found that students held alternative conceptions about the definition of a planet, and about Pluto's size and orbit. There was a significant change from pre- to post-test on students' understanding of why scientists changed the definition of a planet after they engaged with the text.

This finding was accompanied by more positive emotion at post-test. This shift in students' emotions about Pluto's reclassification may have resulted from their reading of the refutation text and finding the scientific rationale for Pluto's reclassification acceptable. A series of regression tests revealed a relationship between students' emotions and their conceptual development. At post-test, positive emotion was a strong predictor of students' belief that Pluto should no longer be a planet, the accepted scientific viewpoint. Positive emotion was also a predictor of students providing scientific reasoning for their decision. In summary, if students felt positive emotions after engaging with the refutational text, they were more likely to hold scientifically accurate conceptions about the definition of a planet and Pluto's reclassification as a dwarf planet. This was one of only two studies reviewed to consider conceptual change from an affective perspective (see Section 2.4.4.1).

Physical models. The review identified three studies that investigated the use of physical models in facilitating scientific conceptions. In one study, pre-service teachers worked in groups to create models to represent the Earth-moon-sun system and presented their model to their peers (Ogan-Bekiroglu, 2007). In another study, undergraduate science students created multi-modal models of the Earth's interior (Steer, Knight, Owens, & McConnell, 2005). The final study was a phenomenological study that reported on one primary school teacher's experiences of conceptual change throughout a professional development program on the moon's phases (Shen & Confrey, 2007). Throughout the program, the teacher constructed a variety of physical models to represent the phases of the moon. Initially, she constructed a table using data on moon phases. She then transformed this table into a two-dimensional diagram, and finally a three-dimensional model.

Each of these studies employed different approaches to data generation. A range of data sources was used, including video recordings, interviews, diagrams and questionnaires. While two studies utilised a typical qualitative approach to data analysis and coded participants' pre- and post-treatment responses on a questionnaire/drawing task (Ogan-Bekiroglu, 2007; Steer at al., 2005), one study took a novel approach and analysed the participant's real-time conceptual change by video-recording her experience (Shen & Confrey, 2007). The authors of this study looked primarily for discussion and debate occurring during group discussions (often revealing the teacher's alternative conceptions and instances of conceptual change). This allowed the researchers to capture the cognitive processes embedded within social interactions, which they argued is key to understanding conceptual change and is in accordance with the conditions of regular schooling. Despite the merit of video-recording participants during the intervention, this was an uncommon approach to data collection.

All of the instructional approaches where participants were constructing or manipulating physical models were found to be effective. A significant finding from one study was that profound conceptual development occurred when transforming information between models and constructing multiple representations (Shen & Confrey, 2007). This was attributed to the participant being actively involved in the modeling tasks, likening one representation to another, and resolving inconsistencies within and between models. Although the findings from another study suggested that such an approach is effective overall, the authors cautioned against the use of student-generated models (Ogan-

Bekiroglu, 2007). Some pre-service teachers in this study retained their pre-instructional alternative conceptions due to limitations of the model they constructed, supporting an earlier finding by Trundle et al. (2002). This was probably because the teacher did not play an active role in checking that the models were scientifically accurate. Despite this, and based upon the positive results of the use of models as evidenced in these studies, it appears that a call for further research into the use of models in learning Earth and space science concepts, particularly geological phenomena such as plate tectonics, is justified (Steer et al., 2005).

Analogy. Two studies investigated the effect of teaching elementary school students about the rock cycle using the analogy of aluminum can recycling (Blake, 2001, 2004). Students were introduced to the target (i.e., the rock cycle), taught the analogue (i.e., aluminum can recycling, which students had leant about previously), and then connected the two. Afterwards, students pointed out some limitations of the analogy. Data were gained from multiple sources, including a rock sorting task, concept maps and semi-structured interviews. Students that participated in this treatment were more able to scientifically describe and classify rocks. Blake (2004) suggested that the use of an analogy might have assisted students to construct scientific conceptions of the rock cycle by making links to their prior knowledge. However, one major limitation evident in this study is that the data generally failed to give information about if and how the use of an analogy facilitated conceptual development. This was perhaps because no data sources provided an in-depth examination of the learning occurring throughout the intervention. Repeating this type of research with a deliberate focus on audio-recording students during the learning episode is a possibility for future research.

Cognitive conflict. Tsai and Chang (2005) propose a specific instruction based on creating cognitive conflict as an approach to bringing about conceptual change. They carried out a quasi-experimental investigation to determine the effect of the instruction on Year 9 science students' conceptions about the cause of seasons. While students in one class experienced regular instruction, students in another class were presented with a 'discrepant statement' (e.g., "in winter, the Earth is slightly further from the sun, whereas in summer the Earth is closer to the sun") and a 'critical statement' ("if seasons were caused by Earth's distance to the sun, the Northern and Southern Hemispheres would have the same season at the same time") (Tsai & Chang, 2005, p. 1093) at the beginning of instruction. Following this, the teacher presented both classes with a scientific explanation. During this part of instruction, students were engaged in modeling the Earth's rotation around the sun with balls. Interviews were conducted one week, two months and eight months after the treatment. At each interview, students in the intervention class held more scientific conceptions and fewer alternative conceptions than those in the control class; therefore, this study endorses the use of cognitive conflict based instructional approaches as an effective means of promoting conceptual change. The limited publications in this area and the promising results of this study warrants further research into cognitive conflict as a conceptual change approach in other Earth and space science education contexts.

Student-generated animation. Student-generated animations that do not require specially designed software, such as slowmation (i.e., a from a stop-motion animation), is a new approach that has been researched from a conceptual change perspective very recently (Nielsen & Hoban, 2015). The construction of a slowmation representation is a process whereby an animation is created from a series of still digital photographs that are displayed in quick succession. The creation process involved three broad stages: (1) planning; (2) chunking and sequencing information; and (3) constructing and reconstructing. In the slowmation construction process, the participants of this study researched a topic and then planned a storyboard. They used their own mobile phone or a digital camera to photograph a multi-modal two-dimensional or three-dimensional model as they manipulated it to demonstrate a concept or process. Their photographs were then displayed at two frames per second using software or an iPhone/iPad™ application.

This approach was effective in promoting pre-service teachers' scientific conceptions of moon phases from pre- to post-interview (Nielsen & Hoban, 2015). In creating a slowmation, the pre-service teachers demonstrated their understanding of moon phases using different modes; for example, research notes and storyboards, three-dimensional models, still images and narration. This was particularly effective at bringing about conceptual change as the pre-service teachers were presented with multiple opportunities to consider and revise their own alternative conceptions. Comparing their own representations with expert representations was deemed essential in bringing about conceptual change, as was the process of constructing and manipulating physical models (Nielsen & Hoban, 2015).

Other specific teaching and learning sequences. Twenty-three studies reported a variety of other instructional approaches that do not fit within the previous categories. Instructional interventions in this category were generally a mix of teaching and learning activities over a long period of time where the influence of a specific approach could not be delineated. Some examples included:

- An undergraduate astronomy course where concept mapping and group discussions were emphasised (Zeilik, Schau, & Mattern, 1999);
- A unit of work on six astronomical concepts that spanned several weeks and included learning activities such as internet-based research, observations of the moon, and the use of a three-dimensional computer model (Barnett & Morran, 2002);
- An excursion to a planetarium (Chastenay, 2016; Stover & Saunders, 2000);
- Diverse instruction that challenged more than one of students' alternative conceptions simultaneously (Hayes, Goodhew, Heit, & Gillan, 2003); and
- An audio-tutorial that included explanations, guidance for analytical observation of visuals, and instructions for manipulating concrete props (Nussbaum & Sharoni-Dagan, 1983).

2.4.5 Interpretation

The most obvious trend in the existing literature is that intervention studies carried out in the Earth and space science discipline employed what are now considered outdated theoretical and methodological perspectives. The major theoretical shortcoming was that almost all of the studies viewed conceptual change from a cognition-only perspective. Although this approach is now being challenged in other science disciplines, researchers are yet to substantially challenge traditional notions of conceptual change in the Earth and space science discipline. Only two studies considered conceptual change from an affective perspective; the remaining studies viewed conceptual change from a cognition-only perspective. There were also a number of methodological shortcomings. First, the learning of astronomical phenomena received significantly greater attention than geological phenomena. Of the 52 studies included in this review, only eight studies investigated the effectiveness of an intervention designed to facilitate scientifically accurate conceptions of geological phenomena. Second, intervention studies in the Earth and space science disciplines have generally investigated conceptual change by measuring students' conceptions pre- and post-intervention. The few studies that generated data throughout the implementation of an instructional approach had a more robust evaluation of the intervention, and provided additional insight into how the instructional approach influenced students' conceptual change. This was an atypical approach to data collection; only three studies included in this review video-recorded participants while they were learning. Third, intervention studies primarily required participants to view or manipulate representations of phenomena. Notwithstanding the effectiveness of this approach, in studies where conceptual change was most profound, participants were creating representations (or multiple representations) of phenomena.

In light of these assertions, there is a clear need for conceptual change research in the Earth and space science disciplines that: (1) challenges traditional notions of conceptual change by considering data from affective perspectives; (2) focuses on the learning of geological phenomena through the construction of multiple representations; and (3) employs qualitative data collection methods throughout the implementation of an instructional approach. The implications of these recommendations for the current research are now presented.

2.4.6 Implications for the Current Study

This section has presented a review of the literature informing the study's research questions and design. In doing so, the literature review has highlighted the need for research that (1) challenges traditional notions of conceptual change; (2) focuses on the learning of geological phenomena through the construction of multiple representations; and (3) employs qualitative data collection throughout the implementation of an instruction approach. Each of these points will now be addressed, in turn.

2.4.6.1 The need for research that challenges traditional notions of conceptual change

Despite the overwhelming and longstanding argument for further research into the interplay between affective variables and conceptual change (Cobern, 1996; Pintrich et al., 1993; Sinatra & Mason, 2013; Treagust & Duit, 2008; Tytler & Prain, 2010; West & Pines, 1983; Zembylas, 2005), only two of the studies reviewed in Section 2.4 of this thesis took such an approach (Broughton et al., 2013; Cordova et al., 2014). As identified earlier, these studies explored the relationships between prior knowledge, efficacy, interest, emotions and conceptual change. The remainder of the studies viewed conceptual change as a purely cognitive construct.

As outlined in Section 2.3.1, science education researchers have increasingly criticised a cognition-only approach to conceptual change learning. It has been suggested that cognition-only models of conceptual change present an over-rationalised view of learning that fails to consider the role of factors such as motivation, interest, self-efficacy, feelings and emotions as conceptual supports for new knowledge (Pintrich et al., 1993). In fact, it has been acknowledged that adopting a purely cognitive perspective of conceptual change can constrain the interpretation of the learning process (Caravita & Hallden, 1994; Duit & Treagust, 2003). If new research in Earth science education continues to ignore the influence of affective variables on conceptual change, the assumption that affective variables are irrelevant to teaching and learning in a cognitively demanding discipline like science will remain unchallenged (Zembylas, 2005). Research that adopts an affective or multidimensional perspective of conceptual change, therefore, is crucial within this discipline where studies of this nature are virtually non-existent.

An in-depth examination of whether interest plays a role in students’ conceptual change is an example of the type of research that is needed. There have been efforts to explore this in other science disciplines. A common theme emerging from the findings is that this area is under-researched and results are contradictory, substantiating the need for ongoing research. Few studies have investigated how individual or situational interest may bring about conceptual change (Sinatra & Mason, 2013; Treagust & Duit, 2008). Of those that do, some authors report that students' interest relates positively to conceptual change (Andre & Windschitl, 2003), while others argue that highly interested students may be more resistant to change (Dole & Sinatra, 1998). Further research of this nature will challenge traditional notions of knowledge reconstruction and help to clarify the opposing results reported to date. The findings from this type of research can also inform teachers' choice of instructional approach so that classroom environments are conducive to conceptual change.

2.4.6.2 The need for research that employs qualitative data collection throughout the implementation of the instructional approach

Although each of the studies examined in Section 2.4 had a unique methodological approach to determine the effectiveness of an intervention, most data were generated pre- and post-intervention only. While this provides a broad insight into the effectiveness of an instructional approach, a fine-grained analysis of the causal mechanisms of conceptual change is not possible. For example, many of interventions discussed were carried out in a group setting. Much of the conceptual change that was taking place, then, was embedded within a broader social context. The socially driven knowledge reconstruction, probably occurring from dialogue, scientific reasoning and argumentation between participants or between participants and the teacher, could have provided valuable information about how an intervention influenced conceptual change.

Three studies that adopted this approach were able to provide a more robust evaluation of the effectiveness of an instructional approach (i.e., Gazit et al., 2005; Nielsen & Hoban, 2015; Shen & Confrey, 2007). These studies also aligned better with contemporary views on cognitive science, such as the view that learning should support collective knowledge construction (Klein, 2006). By capturing students' real-time conceptual change, the researchers were able to very specifically determine how the instructional approach influenced participants' conceptual change. This is in stark contrast to the studies that could only identify that conceptual change increased from pre- to post-intervention, and then speculate why this had occurred. Future research that employs qualitative data collection throughout instruction (e.g., audio or video recording) will significantly contribute to the conceptual change research in the Earth and space sciences and the conceptual change field more broadly.

2.4.6.3 The need for research that focuses on the learning of geological phenomena through the construction of multiple representations

As already reported, the majority of studies included in this review investigated the effectiveness of an intervention designed to facilitate accurate conceptions of astronomical phenomena. Although important, this finding is not surprising. Traditionally, both students and teachers have not regarded Earth science as prestigiously as the other 'hard' science disciplines, like physics and chemistry (Dawson & Carson, 2013). Similarly, Earth science has received little attention in conceptual change literature compared to the physics and chemistry disciplines, where research of this nature originated. Like these disciplines, however, Earth science deals with abstract and unobservable concepts and processes that students hold many alternative conceptions about. The construct of geological time, for instance, is particularly difficult for individuals to comprehend (Dodick & Orion, 2003). The design of instructional approaches that facilitate accurate conceptions of geological phenomena, therefore, is a broad avenue for future research.

As identified in Section 2.4, the instructional approaches where conceptual change appeared to be most profound were those that required the physical construction of multiple representations (Nielsen & Hoban, 2015; Shen & Confrey, 2007). In these instances, there were many opportunities for participants to consider and revise their alternative conceptions. This finding supports an emerging way of thinking in science education research. Researchers have suggested that 'representational negotiation' should be a significant focus in the science classroom (Klein, 2006; Tytler & Prain, 2010). That is, students should have many opportunities to "integrate, refine, and translate ideas across representations" (Tytler & Prain, 2010, p. 2074). While this is not an entirely new idea that has been researched in other science disciplines such as chemistry, instructional approaches that emphasise opportunities to construct multiple representations of Earth science phenomena are almost non-existent. The use of student-generated animation such as slowmation, however, is one example of how this gap in the research can be addressed.

There is currently a paucity of research on the learning potential of student-generated animations, making it an interesting avenue for future research, particularly from a conceptual change perspective. A number of studies have noted the educational value of students creating animations in chemistry (Chang et al., 2010; Schank & Kozma, 2002; Stieff & Wilensky, 2003; Wilder & Brinkerhoff, 2007; Wu, Krajcik, & Soloway, 2001), while another has examined the learning potential of creating animations in mathematics (Hubscher-Younger & Narayanan, 2007). In these studies, the use of specially designed software packages increased students' conceptual understanding. For example, Year 7 students who used *Chemation*™ software to generate and explain an animation of a chemical reaction had significantly higher post-test scores than students who viewed and explained a teacher-generated animation (Chang at al., 2010). Other specially designed software (*ChemSense*™, *Connected Chemistry*™, *Chemscape Chime*™ and *eChem*™) has also yielded positive learning outcomes when students created their own animation (Schank & Kozma, 2002; Stieff & Wilensky, 2003; Wilder & Brinkerhoff, 2007; Wu et al., 2001).

Student-generated animation that does not require special software, such as slowmation, has been researched to a lesser extent. Research on slowmation outside of the Earth and space science disciplines has been situated in pre-service teacher education contexts. Studies have found that slowmation is highly effective in supporting science pre-service teachers to identify and change their own alternative conceptions of science concepts or processes (Hoban & Nielsen, 2012, 2014; Kidman, Keast, & Cooper, 2012; Nielsen & Hoban, 2015; Loughran, Berry, Cooper, Keast, & Hoban, 2012). An approach such as this, where students are creating multiple representations of science phenomena, appears to be well aligned with contemporary perspectives of learning in science and at the cutting edge of conceptual change research in this discipline (Tytler & Prain, 2010).

2.5 The Potential of Slowmation as a Conceptual Change Approach to Learning in Science

Although notions of conceptual change have developed over the last three decades, there remains a paucity of evidence-based conceptual change instructional strategies (Treagust & Duit, 2008). Recently, student-generated animation has been suggested as an efficient approach for bringing about conceptual change in science. This section will consider the potential of one type of student-generated animation, slowmation, in learning science.

2.5.1 The value of student-generated animation in science education

Animations are particularly suited to the sciences as they can be used to illustrate effectively abstract concepts that change over time or are otherwise unobservable. Student-generated animations that do not require specially designed software, such as slowmation, have been researched recently in light of the value of engaging students in the construction and manipulation of multiple representations. As outlined in Section 2.4.4.2, slowmation is a process where an animation is created from a series of still digital photographs that are displayed in quick succession (Hoban, 2005, 2007). The creation process involves three stages: (1) planning, (2) chunking and sequencing information, and (3) constructing and reconstructing (adapted from Hoban & Nielsen, 2012). In the slowmation creation process, students research a topic and then plan a storyboard. They use a mobile phone or digital camera to photograph a multi-modal, two- or three-dimensional model as they manipulate it to demonstrate a concept or process (generally, the model is flat on a table or on the floor). The photographs are then displayed at about two frames per second using computer software such as *MovieMaker*™ or a mobile phone application such as *MyCreate*™.

Slowmation has been most widely researched in pre-service teacher education contexts. Studies have found that slowmation is effective in facilitating science pre-service teachers to identify and resolve their own alternative conceptions of science concepts or processes

(Hoban & Nielsen, 2012, 2014; Kidman et al., 2012; Nielsen & Hoban, 2015; Loughran et al., 2012). To illustrate, a group of pre-service teachers had their understanding of biological fitness questioned by their peers as their slowmation ('Survival of the Fittest') showed a beetle being eaten by a frog, which in turn was eaten by a snake, and so on. A pre-service teacher from another group argued that they had confused the concept of 'survival of the fittest' with the conception of a food chain (Loughran et al., 2012). Slowmation has also been researched in school contexts, albeit to a lesser extent than pre-service teacher education. The construction process has been shown to bring about positive learning outcomes (e.g., Brown, Murcia & Hackling, 2013; Hoban, Ferry, Konza & Vialle, 2007; Jablonski, Hoban, Ransom & Ward, 2015; Kidman & Hoban, 2009), despite the seemingly high level of 'representational competence' necessary when making knowledge claims using representations (elaborated further in the section below).

2.5.2 Positioning slowmation within a theoretical framework

Multiple theoretical frameworks have been used to understand better the learning that occurs during the creation of a slowmation representation. One useful framework is semiotics. Peirce's (1931) triadic model of a semiotic system shows that there is a relationship between: (1) the concept being represented (i.e., the referent); (2) the representation itself; and (3) the meaning generated from the representation. The process of creating a slowmation representation, then, can be viewed as a dynamic process, "as the student makes meaning by iteratively checking the content whilst creating the representation" (Hoban et al., 2011, p. 991).

From this foundation in semiotics, the *5Rs Model* (Hoban & Nielsen, 2010) and the *Meaning-Making through Animation and Editing, Presentation and Explanation, and Reflection (MMAEPER) Model* (Kidman et al., 2012) have been developed. In the 5Rs model, students translate their knowledge through five multi-modal representations (i.e., 5Rs). The five representations are: (1) background notes; (2) storyboard; (3) models; (4) digital photographs; and (5) the final animation (Hoban & Nielsen, 2010; Figure 2.2). The five representations are interrelated "because one feeds into the next" (Hoban &

Nielsen, 2010, p. 6). Also, the combination of representations in the model distinguishes slowmation from other one-off representational forms.

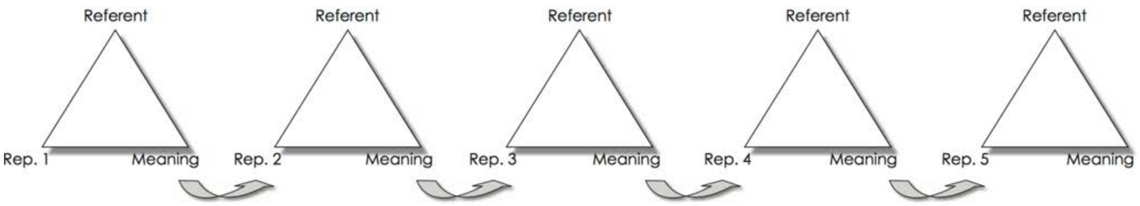

Figure 2.2. The 5Rs model of learning through constructing a slowmation (from Hoban & Nielsen, 2010, p. 35).

The MMAEPER model, which builds on the foundation of the 5Rs model, provides a more in-depth examination of how learning takes place (Figure 2.3). There are two learning pathways in the model: 'surface learning' and 'deep learning'. Surface learning occurs during the construction of a slowmation if students use existing representations from textbooks or the Internet (rather than creating their own), and if students do not consider the scientific accuracy of their representations. Deep learning, such as conceptual change, on the other hand, is shown to be an iterative cycle whereby the scientific accuracy of the representation is considered multiple times (Kidman et al., 2012). Importantly, the teacher has a significant role to play in facilitating students' consideration of the accuracy of their representation, as shown at points C and D on Figure 2.3. The MMAEPER model has recently been further refined through a transformative learning framework to include 'meaning-making' and 'meta-learning' pathways (Kidman, 2016). Elements from both the 5Rs and MMAEPER model were used to inform the enactment of slowmation in the current study, as is detailed in the next chapter.

The notion that learning occurs through the construction of *multiple representations* is common to these theoretical frameworks. Notwithstanding the advantages of learning science with multiple representations (e.g., Ainsworth, 1999; Hubber, Tytler, & Haslam, 2010), there are a range of complexities that accompany their use. Ainsworth (2008) notes that the most fundamental competency students must develop is an understanding of representational syntax. This refers to (1) how a representation encodes and presents information, and (2) its relationship to the topic it is representing (Ainsworth, 2008). This understanding of representational syntax has implications for students' interpretation (or misinterpretation) of representations. Ainsworth (2008) also notes that learning with multiple representations requires an understanding of how to select and construct appropriate representations, and, of particular relevance to the slowmation construction process, how to relate multiple representations to one another. In summary, it seems that students require a certain level of 'representational competence' (Kozma & Russell, 1997; Lemke, 2003; 2004; Prain & Tytler, 2012) in order to access the type of learning required by representation construction tasks, including slowmation.

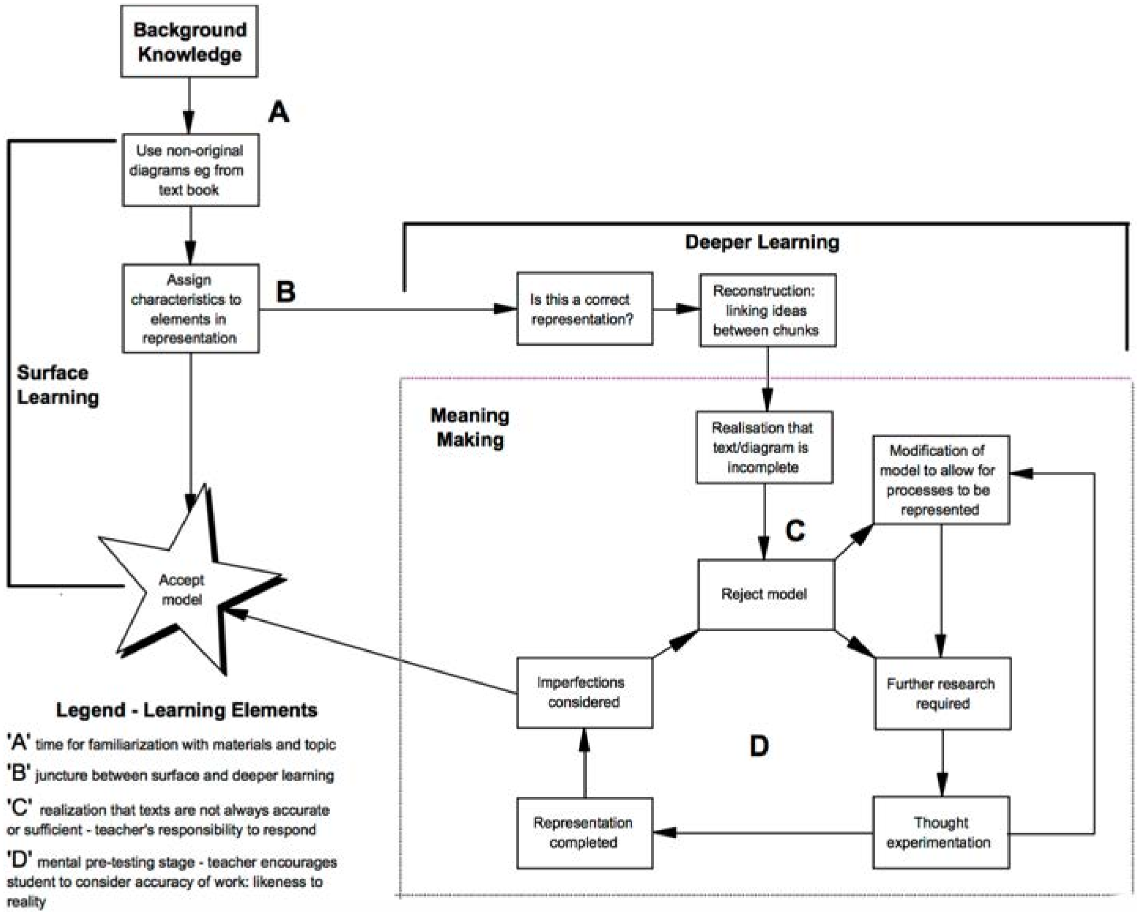

Figure 2.3. The MMAEPER model of learning and re-relearning through slowmation (from Kidman et al., 2012, p.29)

2.6 Chapter Summary

This chapter has detailed the literature that informed the project's research aims and design in response to evidence of students' firmly held alternative conceptions about Earth science phenomena, and the identified need for innovative conceptual change instructional approaches in this discipline. Section 2.2 provided a general introduction to constructivist learning in science. A critical review of conceptual change literature, including the development of affective perspectives over the past three decades, was provided in Section 2.3. Section 2.4 presented a systematic review of conceptual change instructional approaches used in the Earth and space science discipline. It outlined conceptual change approaches that have been used previously, and methods that have been employed to evaluate the efficiency of those approaches. Section 2.5 detailed the scope of current research on slowmation in science education, and the existing pedagogical models aligned with its use, in response to recent studies that have suggested it is an efficacious conceptual change approach in science education. As outlined in Section 2.4.6, the literature has informed the research design of the current project, ensuring it makes a significant contribution to the existing conceptual change literature by adopting a cognitive-affective perspective of conceptual change; extends conceptual change research in the Earth science discipline; and extends research that investigates the learning potential of slowmation. The following chapter will present an overview of the research design and the methods of data generation and analysis that were employed to answer the research questions.

CHAPTER THREE: RESEARCH DESIGN AND PROCEDURES

3.1 Chapter Introduction

As demonstrated in the previous chapter, the aim of this research project was to investigate how constructing a slowmation influenced students' conceptual change, and the relationship between students' interest generated by the project and their conceptual change. The research questions supporting these aims are:

1. Does the process of constructing a slowmation have a significant effect on students' conceptual change in Earth science?
2. How does the process of constructing a slowmation influence students' conceptual change?
3. Is students' interest, generated by the construction of a slowmation, a significant predictor of conceptual change?

This chapter will outline the research project's design and the procedures employed to answer each research question. It is presented in four main parts. Section 3.2 will describe the mixed methods intervention design and justify its suitability for answering the research questions. Section 3.3 will detail the school and class contexts where the research was carried out. Section 3.4 will outline the research project's procedures, including the project's organisation (Section 3.4.1) and approach to data generation and analysis (Section 3.4.2). These sections will demonstrate how quantitative and qualitative methods have been integrated to answer the research questions. Finally, Section 3.5 will acknowledge the research issues and limitations.

3.2 Research Design

This research project adopted a quasi-experimental, mixed methods intervention design (Creswell, 2015) in order to answer the three research questions. This approach combines the strengths of both quantitative and qualitative data. While quantitative data enables the identification of trends that can be generalised across a population, qualitative data facilitates a deeper understanding of individual participant's experiences in a given context (Creswell, 2005).

The principal aim of this study is to determine whether the process of constructing a slowmation has a significant effect on students' conceptual change. Since experimental research is concerned with determining a cause-effect relationship, is it well-suited to this aim (Lankshear & Knobel, 2004; Taber, 2013). In a true experiment, the researcher controls the variables so that only the factor that is hypothesised to have an effect differs between the intervention and comparison groups. Such control is rarely possible in naturalistic, classroom-based research; however, it is sometimes possible to make comparisons between situations that approximate the conditions needed for an experiment. Therefore, a quasi-experimental (non-equivalent groups) design was employed. This approach, despite some limitations, is used extensively in science education, and, as identified in Chapter 2, has been previously used to evaluate the effectiveness of conceptual change instructional approaches in astronomy and geology education contexts (e.g., Trundle et al., 2002; Trundle & Bell, 2010; Tsai & Chang, 2005).

Although a dichotomy has traditionally existed between positivist and interpretivist research philosophies, and qualitative and quantitative research methodologies, considerable literature now supports a pragmatic research paradigm that uses mixed methods (Creswell, 2005). Research that is conducted within the pragmatic paradigm is problem-centred. This means that methods of data collection and analysis are chosen based on their capacity to answer the research questions, rather than a philosophical commitment to a given research paradigm (Mackenzie & Knipe, 2006). This was the approach adopted in the current study, as the mixed methods chosen to answer the research questions are both quantitative and qualitative, and associated with positivist and interpretivist research paradigms, respectively. This approach combines the strength of both types of data, in that quantitative data enables the identification of trends that can be generalised across the sample populations, while qualitative data facilities a deeper understanding of the context (Creswell, 2005).

In this study, therefore, data were generated from four Year 9 science classes (N=95) at a Preparatory to Year 12 college in South-East Queensland, Australia. While students in two intervention classes (N=52) worked in groups to create a slowmation, students in two comparison classes (*N*=43) followed the school's usual program of instruction (i.e., 'teaching as usual'). Quantitative data were collected from all four classes before and after their participation in the research project. The GeoQuiz, a two-tiered multiple-choice test, was used to examine students' conceptual change, while the SILS survey was used to measure their interest. Additional qualitative data were collected from the two intervention classes. Several groups of students from the intervention classes (*N*=19) were audio-recorded while they constructed their slowmation, and the same students participated in a post-intervention interview. This allowed the researcher to gain a more in-depth insight into how the process of creating a slowmation influenced students' conceptual change, and the role, if any, that students' interest played in bringing about conceptual change. Figure 3.1 illustrates the mixed methods intervention design of the research project.

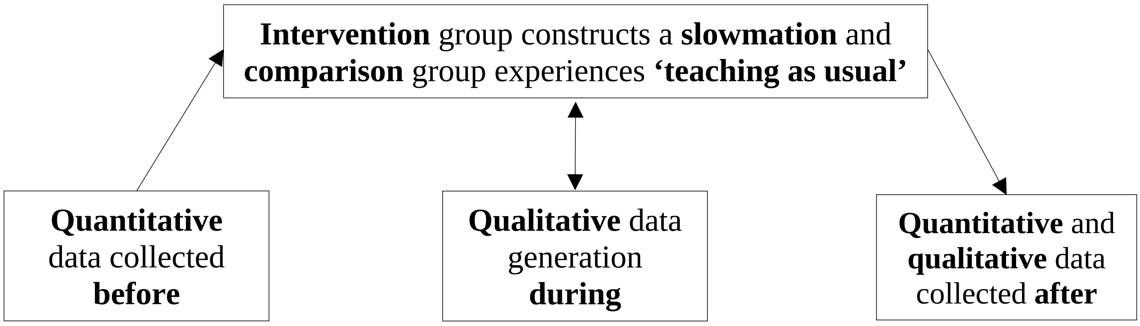

Figure 3.1. A representation of the mixed-methods intervention design adopted in the research project.

Within a school setting, it is not practical (or possible) to randomly assign individual students to intervention and comparison groups. Therefore, this study randomly assigned four intact science classes to an intervention or comparison condition. A tandem matched-pairs approach was adopted within the broader experimental design (Randler & Bogner, 2008). This meant that there were two pairs of intervention and comparison classes, and each pair had the same teacher (Figure 3.2). By adopting this approach, the researcher increased the comparability between each pair of grouped students (Randler & Bogner, 2008). The researcher statistically investigated two independent variables that might have influenced students' conceptual change (namely, class teacher and gender) during data analysis.

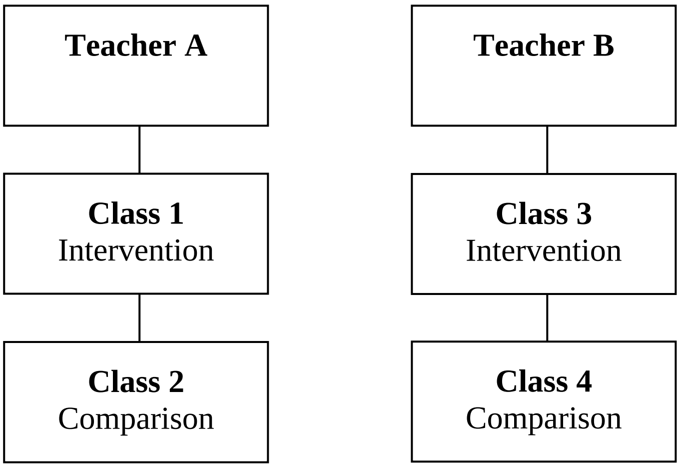

Figure 3.2. A representation of the tandem matched-pairs approach adopted in the current study.

3.3 The School and Class Contexts

The college at which this study was conducted, Pine Mountain State College (a pseudonym), is one of the largest schools in Queensland, with almost 3000 students enrolled from Preparatory to Year 12 (ACARA, 2015). Two per cent of students identify as Aboriginal or Torres Strait Islander and 15 per cent have a language background other than English (ACARA, 2015). The College has a high Index of Community Socio-Educational Advantage (ICSEA), which means that students at the College come from an educationally advantaged background (ACARA, 2015). The College only services the immediate community, which means that the students generally have uniform cultural and socioeconomic backgrounds.

The College is structured as a series of ‘sub-schools’. There is a Lower Primary School (Year P-4), Upper Primary School (Year 4-6), Middle School (Year 7-9) and Senior School (Year 10-12). In the Middle School, where this project was situated, the curriculum is structured around five core subjects: Mathematics, Science, English, History and Geography. The students also choose from elective subjects, including The Arts, Technology, Business Studies, Italian, and Health and Physical Education.

During the project's implementation, Year 9 science students were completing a unit of work from the *Earth and Space Sciences* sub-strand of the *Foundation to Year 10 Australian Curriculum: Science* (ACARA, 2016). The unit of work is a C2C unit called *'Changing Earth'* (DETE, 2014a). This unit of work was common to Queensland students enrolled in state schools at the time of the implementation of the intervention.

Four classes and two teachers were involved in the research project. The science classes at Pine Mountain State College are not streamed according to previous academic results; therefore, the students in the selected classes demonstrated a range of achievement levels. Some variation was noted in students' medical and cultural backgrounds. Some of the students in the four classes speak English as a second language, or present with additional learning needs (i.e., a state government verified disability or a learning difficulty). Other students were identified as gifted and talented by the College. The classroom teachers recommended that no differentiation was necessary in the delivery of the project, as all students could participate equitably. The teachers involved in the research project were experienced, and had each been teaching for more than 10 years across junior and senior secondary science contexts.

3.4 Research Procedures

The following section is presented in two main parts. First, it describes how the research project was implemented across three stages. Second, the methods of quantitative and qualitative data generation and analysis are described to illustrate how the research questions were answered.

3.4.1 Organisation

The research was carried out in three stages. In the first stage of the research project, which occurred in Term 1, 2015 (26/01/15–03/04/15), the researcher developed and validated a two-tiered multiple-choice test that was used to identify students' alternative conceptions before and after their participation in the research project. The GeoQuiz tests students' understanding of geologic concepts specific to the unit *'Changing Earth'* (DETE, 2014a). The process that was followed involved three major tasks: (1) defining the content; (2) researching students' alternative conceptions; and (3) developing and validating the final instrument (Treagust, 1988). Each of these tasks is described in detail in Chapter 4. A justification for the use of a two-tiered test is also given later in the next chapter.

In the second stage of the research project, which also occurred during Term 1, 2015 (26/01/15–03/04/15), a pilot study was conducted at the research site. This was carried out to gain further insight into the use of slowmation with school-aged learners, given the paucity of research conducted within this context (Chapter 2, Section 2.5.1). Stage 2 of the project involved teaching the relevant teachers and students how to create a slowmation, and familiarising the students with think-aloud protocols and the data collection equipment (namely, audio-recording devices). The two teachers involved in the research project completed an hour-long training course delivered by the researcher during a faculty meeting. The researcher taught his colleagues about the purpose of a slowmation representation, how to use the *MyCreate*™ application, and they co-constructed an example slowmation. Then, students practised making a slowmation that explained the flow of electricity through a circuit. During this process, the students were audio-recorded and these data were analysed by the researcher to inform the implementation of the project later in the year.

In the third and final stage, the research project was implemented. Data collection in this phase, as reported in this thesis, occurred in Term 2, 2015 (20/04/15–26/06/15). Students worked in pairs or groups of three to co-construct their slowmation representation over four 70-minute lessons with their respective classroom teacher (students chose their own groups and these were amended by the teacher if deemed necessary). In determining the topic of students' slowmations, the researcher identified the most common alternative conceptions held by students using the results of the GeoQuiz administration during stage one (i.e., development of the instrument). As most of students' alternative conceptions were about tectonic plates and tectonic plate boundaries, it was decided that students would create a slowmation that explains the geological processes that occur at a tectonic plate boundary of their choosing. The researcher administered the GeoQuiz and SILS survey to all classes pre- and post-intervention. This occurred in the lesson prior to students beginning construction of their slowmation representation and the lesson immediately after completion (i.e., the administration of the test and questionnaire occurred outside of the four 70-minute lessons).

The slowmation construction process included three broad stages: planning, construction and presentation (adapted from Hoban & Nielsen, 2012). During the planning phase, students researched a type of tectonic plate boundary using the Internet and created a storyboard for their slowmation representations. The storyboard showed what materials the students would manipulate and how they would be manipulated between each still photograph in order to represent their chosen tectonic plate boundary. Students had a range of craft materials available for use, including coloured paper, modeling clay, sponges, pipe cleaners, paddle-pop sticks, markers and labels. In the construction phase, students constructed, manipulated and photographed their representations of a tectonic plate boundary using iPads™ that had the *MyCreate*™ application installed. Students used the application to display the photographs at one second per frame and added narration that explained the processes occurring. Finally, students viewed their peers' animations in the presentation phase. To enhance the authenticity of the task, the Year 9 students presented their finished slowmation representations to the College's younger children. A summary of the task presented to students is presented in Figure 3.3.

A constructivist learning environment was encouraged throughout the implementation of the project. This means that students were supported to independently translate information between representations, consistent with the 5Rs model (Chapter 2, Section 2.5.2) and identified studies where this brought about conceptual change (Nielsen & Hoban, 2015; Shen & Confrey, 2007). The role of the classroom teacher, as identified in the MMAEPER model (Chapter 2, Section 2.5.2), was to ensure that students represented scientifically accurate information throughout each stage of the construction process. In doing so, the teacher moved between groups of students and prompted them to consider the accuracy of their research notes, storyboards, models, images and final animations. The teacher also prompted students to verbalise their thinking and explain their approach to completing each of the stages. The researcher adopted an observer-participant role (Creswell, 2015), and assisted with these tasks only if approached by a student. It is to be noted that although a constructivist learning environment was encouraged, the researcher had little control over the teachers' and students' perspectives of learning in science, nor the type of learning environment that was normally established in the classroom.

Teaching as usual for the two comparison classes comprised the College's enactment of the Australian Curriculum; namely, the learning activities provided in the C2C unit '*Changing Earth*' (DETE, 2014a). While the intervention classes were creating slowmation representations, the comparison classes participated in the corresponding C2C lessons. This meant that over the four science lessons, all four classes involved in the project learnt the same underlying content about tectonic plates and tectonic plate boundaries. Example learning activities from the *'Changing Earth'* (DETE, 2014a) unit plan include viewing a PowerPoint™ presentation about plate tectonics, drawing and labeling diagrams of the earth's layers and plate boundaries, watching short videos on YouTube™, and engaging with interactive internet-based learning objects. Some the learning activities were adapted as necessary to span four 70-minute science lessons (Table 3.1).

Representing Earth Science Concepts Using Slowmation

Name and group members:

Type of tectonic plate boundary:

You are to work in pairs to co-construct a slowmation that explains a tectonic plate boundary ***of your choosing***. Your slowmation should answer the following questions:

1. ***What are tectonic plates?***
2. ***What causes tectonic plates to move?***
3. ***How do tectonic plates interact at your chosen type of tectonic plate boundary?***
4. ***What landforms occur at your chosen type of tectonic plate boundary?***
5. ***How are these landforms created and how long does the process take?***

The construction process will include three stages. These are ***planning***, ***construction***, and ***presentation***:

Planning (Lesson 1)

- ***Use a laptop to research*** a type of tectonic plate boundary
- ***Construct a storyboard*** for your slowmation that shows what materials you will use and how they will be manipulated between each photograph
- ***Write a script*** that explains the science concepts or processes in your slowmation

Construction (Lesson 2 and 3)

- ***Construct, manipulate, and photograph*** your representations using the MyCreate application of your iPad
- Use the application to display the photographs at an appropriate speed and ***record your narration***

Presentation (Lesson 4)

- ***Present your slowmation*** to the class and share what you have learned

Work hard, you will present your slowmation to students from the primary school at the end of the term!

Figure 3.3. *A summary of the slowmation construction task presented to students in the intervention group.*

Table 3.1

The learning sequence enacted in the comparison classes (adapted from DETE, 2014)

Topic	Lesson	Timing	Students' actions
Heat and convection	1	70 min	• Viewed an interactive website about Earth's structure and answered comprehension questions. • Drew annotated diagrams comparing Earth's layers. • Conducted an experiment to model how convection may cause the movement of tectonic plates. • Drew annotated diagrams to explain the findings of the experiment.
Divergent boundaries	2	70 min	• Viewed a PowerPoint™ presentation that explained types of divergent plate boundary. • Modeled the process of seafloor spreading and answered questions. • Drew annotated diagrams to explain the processes that occur at divergent plate boundaries.
Convergent boundaries	3	70 min	• Viewed a PowerPoint™ presentation and videos that explained types of convergent plate boundaries. • Viewed an interactive website and answered questions. • Drew an annotated diagram to explain the processes that occur at convergent plate boundaries.
Transform boundaries and summary	4	70 min	• Viewed an interactive website that explained transform plate boundaries and answered questions. • Viewed an interactive website that compares all types of tectonic plate boundaries and completed a summary table.

The researcher endeavored to implement the project in a manner that ensured any significant conceptual change arising from the intervention classes could be confidently attributed to the use of slowmation. To achieve this, both pairs of intervention and comparison classes were taught by the same teacher, which increased the comparability between each pair of grouped students (Randler & Bogner, 2008). Also, although the comparison classes experienced teaching as usual, the enacted learning sequence for these classes was still based on students viewing or constructing representations of tectonic plate boundaries (e.g., diagrams and three-dimensional models). As such, the only major difference between the conditions was the multi-representational nature of constructing a slowmation, which required students to transform science information from one representation to another. Other variables (e.g., socioeconomic variables and gender) were comparable given the uniform student body at the College where the research project was carried out (see Section 3.3) and the researcher's choice of statistical tests during data analysis (see Section 3.4.2.1).

3.4.2 Methods of data generation

The project employed mixed methods to generate coarse- and fine-grained data. Data pertaining to students' conceptual change were generated using:

- the GeoQuiz, a two-tiered diagnostic test instrument administered to all students before and after their participation in the research project;
- audio recordings of selected students from the intervention classes thinking-aloud during the creation of their slowmation; and
- semi-structured, in-depth interviews conducted with selected students from the intervention classes at the end of the project.

Data pertaining to students' interest in learning science were generated from the SILS survey administered to all students before and after their participation in the research project; and semi-structured, in-depth interviews conducted with selected students from the intervention classes.

An information sheet and consent form was distributed to each student to inform his/her parents about each stage of the project (Appendix A). Informed consent was collected from each student and their parents to allow the researcher to use all of the data collected during the research project.

3.4.2.1 Two-tiered multiple-choice test: The GeoQuiz

The GeoQuiz was administered pre- and post-intervention to determine if the process of creating a slowmation representation had a significant effect on students' conceptual change. It is to be noted that a delayed posttest was not conducted due to the scope and time constraints of the degree sought. The first tier of each item on the GeoQuiz is a multiple-choice content question. The second tier is a set of possible reasons for the answer given, consisting of the correct answer and any identified alternative conceptions. Figure 4.2 in the next chapter illustrates the two-tiered structure of the GeoQuiz, and the full instrument is provided in Appendix B.

This type of test instrument was chosen because it is particularly well suited to diagnose students' alternative conceptions in science. Although researchers have broadly used variations of multiple-choice tests to achieve this aim in Earth science, the use of a tiered multiple-choice test is a more "sensitive and effective way of assessing meaningful learning" (Treagust, 2006, p. 3). It also overcomes the limitation of a traditional multiple-choice test whereby a student can rote-learn or guess content-only items.

The nine items on the GeoQuiz are specific to the research project. The items test for students' alternative conceptions about tectonic plates and the formation of landforms at tectonic plate boundaries. The GeoQuiz was scored in a manner consistent with practice described in the literature (Table 3.2). Students were considered to hold an alternative conception if they gave an incorrect answer and an alternative reasoning. An alternative conception was deemed significant if it was held by at least 10% of the students (e.g., Chu, Treagust, & Chandrasegaran, 2009).

Table 3.2
Scoring rubric for the GeoQuiz

Response	**Score**
Correct answer and scientific reasoning	3
Incorrect answer and scientific reasoning	2
Correct answer and alternative reasoning	1
Incorrect answer and alternative reasoning	0
No attempt at the question	0

3.4.2.2 Student interest questionnaire: The SILS survey

The SILS survey is a Likert-style questionnaire that was administered pre- and post-intervention to all participating classes in order to investigate the relationship between students' interest and their conceptual change (Appendix C). The instrument consists of 23 items that have been directly sourced or adapted from the *2006 PISA Student Questionnaire* (OECD, 2006) and the *Situational Interest Survey* (Linnenbrink-Garcia et al., 2010), both of which have been rigorously validated within the literature. The items gauged students' individual and situational interest in learning about Earth science. Figure 3.4 below shows an example subscale from the questionnaire that gauges students' situational interest in learning about their current Earth science unit of work.

Q3 Think about your experience in science this term. How much do you agree with the following?

	Strongly agree	*Agree*	*Disagree*	*Strongly Disagree*
a) My science teacher is exciting	☐ 4	☐ 3	☐ 2	☐ 1
b) When we do science, my teacher does things that grab my attention	☐ 4	☐ 3	☐ 2	☐ 1
c) My science class is often entertaining	☐ 4	☐ 3	☐ 2	☐ 1
d) My science class is so exciting it's easy to pay attention	☐ 4	☐ 3	☐ 2	☐ 1

Figure 3.4. An example item from the SILS survey.

3.4.2.3 Students thinking-aloud during construction

Audio-recordings of students thinking-aloud as they made their slowmation comprised one of two important sources of qualitative data in this study (see also, student interviews, below). Six groups of students (*N*=19) were audio-recorded throughout the construction of their slowmation (i.e., three groups of students from each intervention class) as they verbalised their thinking about the construction process. These students were chosen to be audio-recorded after a discussion with their teacher, who indicated that they would be capable of clearly articulating their thinking during the construction process. It is to be noted that the comparison group was not audio-recorded. This is because these data were not needed to answer the research questions.

3.4.2.4 Student interviews

Semi-structured, in-depth interviews were the second source of qualitative data used to gain insight into how creating a slowmation influenced students' conceptual change. Interviews were conducted with the same students who were audio-recorded throughout the construction process (*N*=19). Rather than presenting a fixed schedule, a semi-structured approach allowed for the elaboration of important themes that emerged during the interviews (Heyl, 2001). At interview, students were asked questions that probed their experiences of creating a slowmation, and their perceptions on how the experience influenced their learning. Some questions students were asked at interview included, *'Can you tell me about your experience creating a slowmation?'* and *'How do you think creating a slowmation impacted on your learning?'*. In order to enhance the validity of the findings arising from interviews with students, the researcher spoke briefly to students later in the school term to check that his interpretations of their perspectives at interview were fair and representative (Creswell, 2005). Students from the comparison group were not interviewed, as this data was not needed to answer the research questions.

3.4.3 Data Analysis

Quantitative data analysis was carried out to measure changes in students' responses on the GeoQuiz and SILS survey. The analysis techniques that were employed are described in detail in Section 3.4.3.1. Qualitative analysis of the think-aloud data and student interviews were used to complement and gain a deeper understanding of the quantitative findings. The transcription and coding procedures that were employed are described in detail in Section 3.4.3.2.

3.4.3.1 Quantitative analysis

Both item and statistical analyses were performed on the GeoQuiz data. Any changes in students' conceptions from pretest to posttest were initially analysed by using descriptive statistics; specifically, the frequency of students with scientific and alternative conceptions at pretest and posttest was compared within and between the conditions. Following this, multivariate and univariate analyses were carried out on students' overall test scores to determine if the changes in students' understanding of the science content were significant. A repeated measures analysis of variance (ANOVA) was used to examine whether constructing a slowmation had a significant effect on students' conceptual change, and subsequent *t*-tests were used to investigate any identified significant effects.

Multivariate and univariate statistics were also used to explore the differences between students' interest within and between conditions, and to determine if there were significant changes in students' mean survey scores. A multivariate analysis of variance (MANOVA) was conducted to examine the change in students' interest from pretest to posttest. Follow-up ANOVAs and *t*-tests were used to investigate significant effects. Correlation and regression analyses were carried out using the GeoQuiz and SILS survey results to investigate the relationship between students' interest and conceptual change.

3.4.3.2 Qualitative analysis

To facilitate qualitative analysis of student think-aloud and interview data, the researcher first manually transcribed all audio-recordings, using pseudonyms for students' names. Interviews were transcribed in a manner that ensured the subtleties of spoken data were not lost. In doing so, the following procedures, adapted from Psathas (1995), were utilised:

- Emphasis noted by using *italics* for parts of an utterance that are stressed.
- Semi-colons indicate words that are stretched (e.g., so:::).
- Square brackets indicate speech that is overlapped. Double brackets are used when utterances start simultaneously.
- Punctuation indicates pitch: a question mark (?) indicates a question, or rising intonation; a comma (,) indicates continuing intonation; an animated tone is indicated by '!'.
- '=' indicates latching (i.e., no interval between the end of a prior and the start of a next part of talk).

- Numbers in parentheses indicates in seconds the length of an interval [e.g., (2) represents a two-second pause]. Longer un-timed pauses are represented by ((gap)).
- Cut off indicated with a single dash (e.g., bu-).
- Descriptions of phenomena are enclosed in double parentheses [e.g., ((cough)); ((telephone rings))].
- Other than timed intervals, utterances in parentheses are in doubt. If single parentheses are empty, no hearing was achieved.
- '…' indicates an incomplete sentence.

Once transcribed, an initial exploratory analysis was carried out, whereby the transcripts were read several times in their entirety to discern what was important in the data and what was not. During this process, any 'codable moments' worthy of attention were highlighted for ease of reference in later analyses. To code the data, an approach called 'pragmatic eclecticism' was adopted, whereby the researcher kept an open mind throughout the initial data readings and subsequently selected a method that was "most likely to yield a substantive analysis" (Saldaña, 2013, p. 56). Although there was no specific a priori approach to coding the data, the research question *'How does constructing a slowmation influence students' conceptual change?'* was used to focus the analyses.

To begin, 'initial coding' procedures were employed to build a foundation for further coding cycles (Charmaz, 2006; Saldaña, 2013). In doing so, the data were broken down into discrete parts (i.e., the stages of constructing a slowmation used in this study – researching, storyboarding and constructing), closely examined, and compared for similarities and differences. Short segments of text were then coded in a manner representative of their meaning. Throughout this process, the researcher reflected deeply on the content and nuances of the data, and remained open to all possible theoretical directions indicated by his readings (Saldaña, 2013). At times, re-coding was necessary to filter and focus on features of the data that were salient to the research question being investigated. For instance, although student 'talk' may have been considered a form of representation in the current study (e.g., Lemke, 2001), the analysis was filtered to focus on the physical forms of representation identified as pertinent to the slowmation construction process identified in Chapter 2, Section 2.5.2. An electronic catalogue was kept throughout the initial coding process, including the code name, definition, and sample quotations (see Appendix D).

Following this, ‘pattern coding’ procedures were used to develop categories and then themes from the data (Miles & Huberman, 1994; Saldaña, 2013). Pattern codes are “explanatory or inferential” codes that “pull together a lot of material into a more meaningful and parsimonious unit of analysis” (Miles & Huberman, 1994, p. 69). To develop pattern codes, the researcher looked for similarities in meaning among the initial codes. He then categorised and re-labeled similar codes in a manner that holistically captured their ‘spirit’ (Saldaña, 2013). Although this iterative process is difficult to represent, an example of the development of categories and themes from initial codes is shown in Figure 3.5.

Finally, analytical memos were written throughout the process of coding the data in order to document and reflect upon the emergent patterns. The researcher wrote his ‘musings’ in the margins of hard-copy transcripts, and later wrote more formal reflections about the study’s research questions, his code choices and their operational definitions, and any emergent categories and themes (Saldaña, 2013). These actions enabled the exploration of “network relationships between and among concepts” (Saldaña, 2013, p. 45), and created a “rising-above-the-data heuristic” (Saldaña, 2013, p. 41) necessary to formulate meaningful assertions.

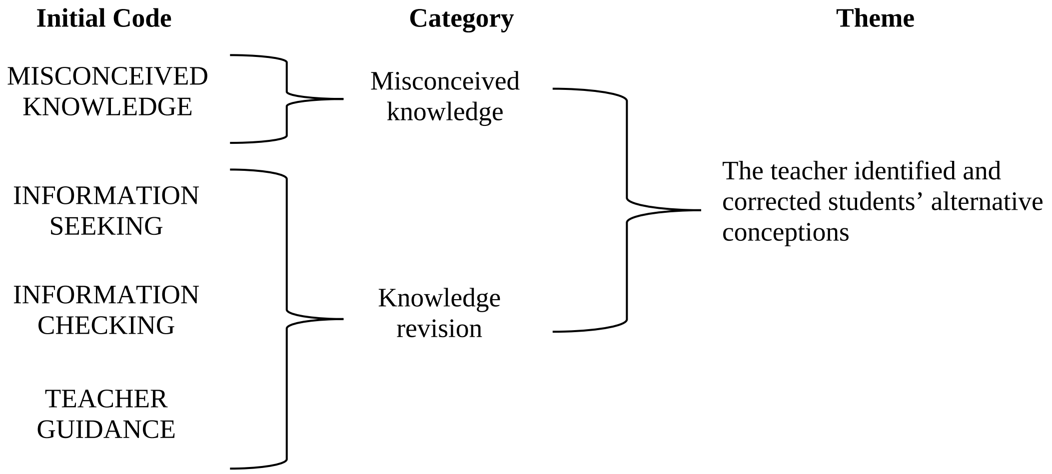

Figure 3.5. Example of how categories and themes were developed from initial codes through pattern coding.

3.5 Chapter Summary

In order to investigate the effect of slowmation on students' conceptual change, and the relationship between students' interest and conceptual change, this study employed a mixed methods intervention design, whereby both quantitative and qualitative data were generated in order to answer the research questions. To determine whether the construction of a slowmation had a significant effect on students' conceptual change, a two-tiered multiple-choice test instrument, the GeoQuiz, was administered to all students in the intervention and comparison conditions before and after their participation in the project. The results from the GeoQuiz were first analysed using descriptive statistics, and then using both multivariate and univariate statistics. A survey that gauged students' interest in learning science, the SILS survey, was also administered to all students before and after the project. Statistical analyses were used to determine if students' participation in the project had a significant effect on their interest in learning about Earth science topics, and whether there was a relationship between students' interest, generated by their participation in the project, and their conceptual change. Finally, think-aloud data and student interviews provided more nuanced data pertaining to students' learning. Transcripts were read multiple times and coded in iterative cycles until substantive themes arose from the data. In order to clarify the procedures described in this chapter, the key stages of the project, including data generation and analysis, and their timing, are presented in Table 3.3. The next chapter will describe the development and validation of the GeoQuiz and SILS survey instruments.

Table 3.3
A summary of the key stages of the study, their timing and the relevant procedures employed

Stage and timing	Procedures
1. GeoQuiz and SILS survey development 26th January to 3rd April, 2015.	The researcher developed and validated the GeoQuiz (a two-tiered multiple-choice test) that was used to identify students' scientific or alternative conceptions before and after their participation in the study.
2. Pilot study 26th January to 3rd April, 2015.	The researcher taught students in the intervention condition how to construct a slowmation and familiarised them with think-aloud protocols. Students constructed a practise slowmation. Anecdotal data were collected in a field journal to inform the study's implementation in the next stage.
3. Project implementation	Four Year 9 science classes participated in the study. Two classes comprised the intervention group and constructed slowmations (*N*=52). Two classes comprised the comparison group and experienced teaching as usual (*N*=43).
3a. Data collection 20th April to 26th June, 2015.	**DATA SOURCES** **GeoQuiz:** All students completed the multiple-choice test immediately before and after their participation in the study. **SILS survey:** All students completed the Likert-style survey immediately before and after their participation in the study. **Students thinking aloud:** Selected students from the intervention classes were audio-recorded during the construction of their slowmation and encouraged to verbalise their thinking and approach to completing the task (*N*=19). **Student interviews:** The students that were audio recorded participated in a post-intervention interview about their experience.
3b. Data analysis September to December, 2015.	**QUANTITATIVE ANALYSES** **GeoQuiz:** A repeated measures analysis of variance (ANOVA) was used to examine whether constructing a slowmation had a significant effect on students' conceptual change. Follow-up *t*-tests were used to investigate significant effects. **SILS survey:** A multivariate analysis of variance (MANOVA) was conducted to examine the change in students' interest from pretest to posttest. Follow-up ANOVAs and *t*-tests were used to investigate significant effects. Correlation and regression analyses were carried out using the GeoQuiz and SILS survey results to investigate the relationship between students' interest and conceptual change. **QUALITATIVE ANALYSES** **Think-aloud and interview data:** These data were analysed for evidence of students' conceptual development. Transcripts were read multiple times and coded in iterative cycles until substantive themes arose from the data.

CHAPTER FOUR: INSTRUMENTATION

4.1 Chapter Introduction

This chapter details the development of the two key instruments employed in this study to generate data pertaining to students' conceptions of plate tectonics, and their interest in learning about Earth science concepts through the project. It is presented in two main sections. First, in Section 4.2, it will describe the development and validation of the GeoQuiz, a two-tiered multiple-choice test instrument that was used to diagnose Year 9 students' alternative conceptions about plate tectonics. Next, in Section 4.3, the development of a questionnaire that gauges students' interest in Earth science (i.e., topic interest) and interest generated by the project (i.e., situational interest) is described: the SILS survey. As identified in the previous chapter, both instruments were administered to all four of the classes that participated in the study, pre- and post-intervention, so as to identify any significant changes in their conceptual understanding and interest over the course of the project.

4.2 Development of the GeoQuiz

There are many two-tiered test instruments available in the literature; however, none were relevant to the unit of work under examination in the current study. It is for this reason that the researcher developed the GeoQuiz, to elicit students' alternative conceptions. The design of the test instrument involved three broad tasks: (1) defining the content; (2) researching students' alternative conceptions; and (3) developing and validating the instrument (Treagust, 1988). The steps to completing each of these tasks, as interpreted in the context of the current research project, are summarised in Figure 4.1, and described in detail in the sections that follow.

(1) Defining the content

- Identified propositional knowledge statements required for understanding of the concepts covered in the Year 9 C2C unit *'Changing Earth'* (DETE, 2014a)
- Created a concept map of the propositional knowledge statements
- Validated the propositional knowledge statements and concept map with experienced science teachers and science teacher educators

↓

(2) Researching students' alternative conceptions

- Searched the literature for common alternative conceptions about continental movement, tectonic plates, and the formation of landforms at tectonic plate boundaries (including the occurrence of geologic events like earthquakes)
- Conducted semi-structured interviews-about-instances (Osborne & Gilbert, 1979) with students to identify additional alternative conceptions

↓

(3) Developing and validating the test instrument

- Developed an initial test instrument
- Designed a specification grid to ensure that the test instrument fairly covers the propositional knowledge statements underlying the topic
- Developed the final test instrument and validated the test using pretest data

Figure 4.1. Approach to the design and validation of the GeoQuiz.

4.2.1 Defining the content

In developing the test instrument, the content boundaries of the unit *'Changing Earth'* (DETE, 2014a) were defined. This was achieved by identifying propositional knowledge statements for the unit (Table 4.1) and developing a concept map that relates the statements to each other (Figure 4.2). These two tasks were important as they allowed the researcher to consider carefully the nature of the content and ensure that the content is internally consistent, as described by Treagust (1988):

> This is a reliability check that the underlying concepts and propositional statements are indeed examining the same topic area. To ensure that the concept area is properly documented it is essential that there is a representative covering of concepts and propositional statements for each topic under investigation. (p. 162)

Table 4.1

Propositional knowledge statements required for understanding the concepts covered in the Year 9 C2C unit 'Changing Earth'

1. The Earth's structure includes the crust, upper mantle, lower mantle, outer core, and inner core.*
2. The lithosphere is the solid outer layer of the Earth made up of the crust and upper mantle. It includes the continents and ocean floor.*
3. The asthenosphere is the partially molten zone in the upper mantle immediately below the lithosphere.
4. The lithosphere is cracked in places, broken up into tectonic plates.*
5. Possible driving forces behind plate movement include convection in the asthenosphere and the pull effect of subducting lithosphere.*
6. At divergent plate boundaries lithospheric plates move apart.*
7. A seafloor-spreading ridge is the most common type of divergent plate boundary and is where new oceanic lithosphere is created.*
8. Seafloor spreading ridge segments are offset by transform faults.
9. A continental rift is a type of divergent plate boundary.
10. At convergent plate boundaries lithospheric plates move toward each other.*
11. A mountain range is a landform that may be formed at a convergent plate boundary.*
12. A subduction zone (and volcanic activity) occurs at convergent plate boundaries where one tectonic plate is pushed under another.*
13. Average rates of plate movement are two to three centimeters per year.*
14. Continental drift suggests that Earth's continents were once joined in one supercontinent called Pangaea.*
15. There are multiple sources of evidence that support continental drift, including matching continental geology (rock types, rock ages, fossils, ore deposits, and so on), paleomagnetism, and polar-wander curves.
16. Continental drift is a process that is measured in geological time, occurring over the past 200 million years.*
17. Volcanoes can form at divergent plate boundaries where magma wells up from the asthenosphere.*
18. Volcanoes (fissures) can form along continental rifts.
19. Isolated areas of volcanic activity not associated with plate boundaries are called hot spots and are likely the result of particularly warm material at the base of the mantle.
20. The stresses involved in convergence and subduction give rise to earthquakes as rock moves*
21. The point on a fault at which the first movement occurs during an earthquake is called the focus.
22. The point on Earth's surface directly above the focus is called the epicentre.
23. When an earthquake occurs, it releases the stored-up energy in seismic waves.
24. P waves are compression waves. That is, as P waves travel through matter, it is alternatively compressed and expanded.
25. S waves are shear waves, involving side-to-side motion.
26. Both types of body waves are detectable using a seismograph.
27. P waves travel faster through rock than S waves and are therefore detected first.
28. The difference in arrival time between the first P and S waves is a function of distance to the earthquake's epicentre.
29. The amount of ground movement is related to the magnitude of the earthquake.
30. The magnitude of an earthquake is most commonly reported using the Richter scale.
31. A Richter magnitude number if assigned to an earthquake based on an adjusted ground displacement measured by a seismograph.
32. The Richter scale is logarithmic.
33. Intensity is a measure of an earthquake's effects on humans and on surface features.
34. An earthquake's intensity is commonly reported using the Mercalli Scale.

Note: The final iteration of the GeoQuiz tested only the propositional knowledge statements marked with an asterix (*). This was an outcome of the validation process and the decision to focus the slowmation on tectonic plate boundaries.

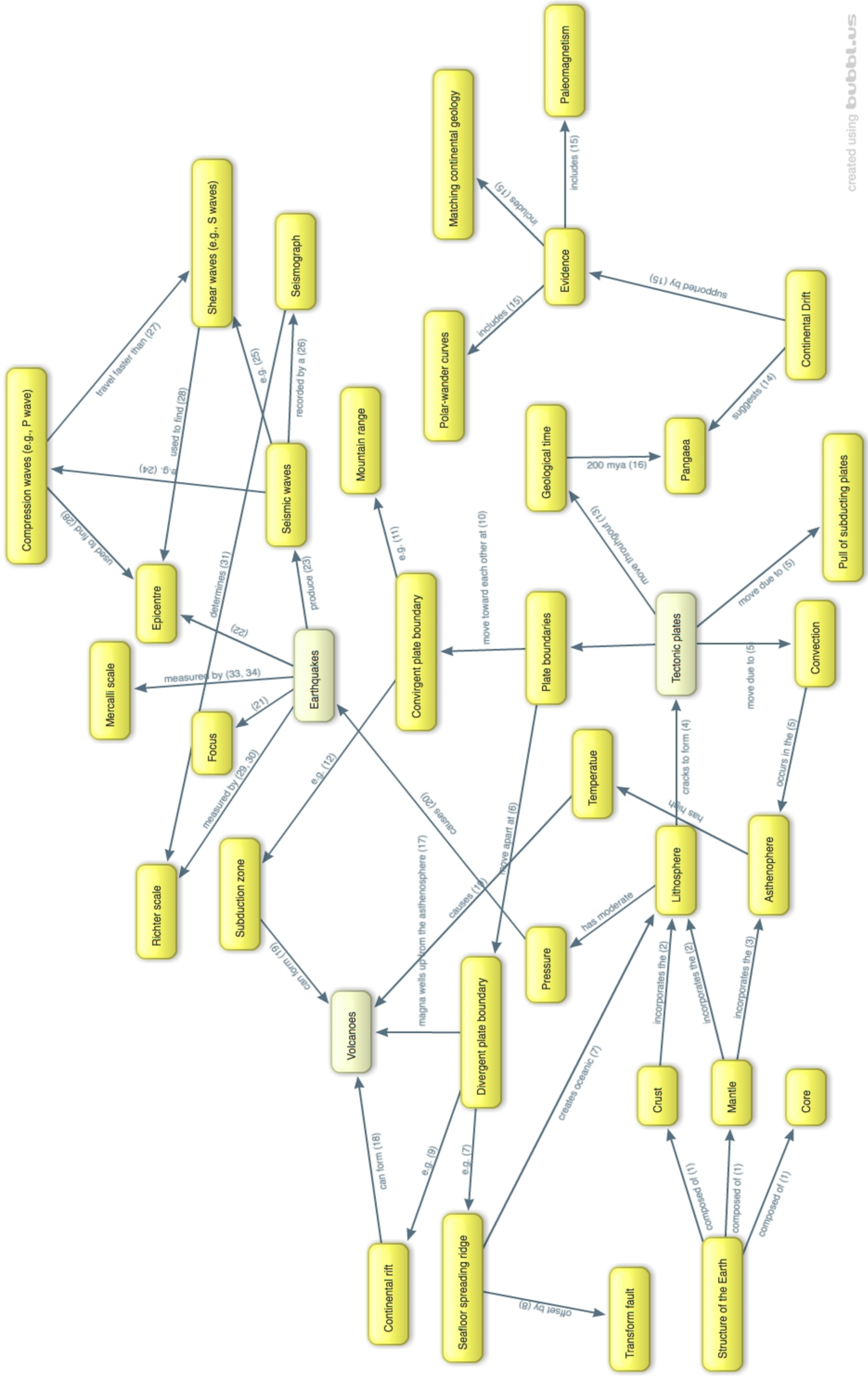

Figure 4.2. Concept map linking the unit's underlying concepts and the propositional knowledge statements written by the researcher.

Experts in the field then validated the propositional knowledge statements and the concept map. The purpose of this was twofold. First, it ensured that the content is scientifically accurate (Treagust, 1988). Second, it ensured that the knowledge being tested is thoroughly documented so that no questions are developed for the test that do not relate clearly to the concepts being taught (Treagust, 1988). In this instance, a panel of four experts validated the propositional knowledge statements and concept map: two experienced Earth science teachers and two science teacher educators. Panel members were asked to indicate if they thought each of the propositional knowledge statements were representative of the understanding required by students in the unit of work (Appendix E). Some of the initial propositional knowledge statements written by the researcher were modified or removed as a result of this process.

4.2.2 Researching students' alternative conceptions

Researching students' alternative conceptions about continental movement, tectonic plates and the formation of landforms at tectonic plate boundaries (i.e., the topics in the *'Changing Earth'* unit of work), provided foundational information for the development of the two-tiered multiple-choice questions. This was achieved in two ways. The researcher first conducted a search of the literature for secondary school students' alternative conceptions about the relevant topics, and then conducted semi-structured interviews with students to identify any additional alternative conceptions.

4.2.2.1 Alternative conceptions from the literature

The researcher found one published study that investigated secondary school students' alternative conceptions about plate tectonics. This study, conducted by Marques and Thompson (1997), reported on Portuguese students' alternative conceptions of continental movement and plate tectonics. Students aged between 16 and 19 years (N=270) held several alternative conceptions about plate tectonics. The authors collected data from students' written responses to open-ended questions. The most common alternative conception, held by 64% of students, was that tectonic plates are stacked on top of each other, in layers. Students that had this perspective thought that the oldest plates comprised the bottom layers, while the youngest plates comprised the top layers. Twentyone per cent of students incorrectly thought that the coastlines of continents are the edges of tectonic plates. It was suggested that terminology used in science classes that refers to ‘two types of plates’ – continental and oceanic – might reinforce this alternative conception. Other alternative conceptions arising from their study were: the same processes produce both continental and oceanic mountain ranges (40%); tectonic plates move about a center axis (35%); and magnetic polar wandering causes the movement of tectonic plates (34%).

4.2.2.2 Alternative conceptions from interviews-about-instances with students

Many more alternative conceptions were uncovered by the researcher’s own interviews with students. A sample of Year 9 students (*N*=21) participated in individual interviews-about-instances (Osborne & Gilbert, 1979). In line with how this method has been used in science education, the researcher used photographs to prompt students’ consideration of particular concepts concerning plate tectonics, and ensured that students voiced aloud the reason for their response. Examples of the questions asked at interview include:

- Is this a photograph of a tectonic plate? Why do you think that?
- This is a satellite photograph of the Andes mountain range in South America. Is this a tectonic plate boundary? Why do you think that?
- These photographs were taken in Christchurch, New Zealand, after the earthquake that occurred there in 2011. What do you think caused this earthquake? Why do you think that?

As the interviews were semi-structured, the researcher did not strictly adhere to an interview schedule. Rather, he pursued courses of fruitful dialogue as they arose and sought out opportunities for gaining an in-depth understanding of students’ conceptions.

Interviews with students typically lasted 20 minutes, and were audio-recorded and transcribed by the researcher for analysis. An initial exploratory analysis was performed by reading all transcripts in their entirety several times to gain a general sense of the data. Following this, the transcripts were divided into segments of text and coded according to their meaning using *NVivo*™ software. An initial framework used for coding was adapted from previous research on students’ alternative conceptions of Earth science phenomena.

Variations of this framework have been used previously to analyse school and university students' conceptions of Earth and space science topics, including moon phases (Nielsen & Hoban, 2015; Trundle et al., 2002) and tides (Ucar et al., 2011), but not students' conceptions about plate tectonics. This framework categorised students' responses as 'no conception' (e.g., "I don't know"), 'incomplete or alternative conception' (e.g., "Whether it's hot underground will determine whether it's a volcano or mountain"), and 'scientific conception' (e.g., "The lithosphere is broken up into tectonic plates"). In alignment with the researcher's aim for this exercise, special attention was then given to identifying alternative conceptions.

It was found that students held many alternative conceptions about plate tectonics, most of which have not been reported in previous research. The data are presented here as follows: (1) students' conceptions about the nature and movement of tectonic plates; (2) students' conceptions about tectonic plate boundaries; and (3) students' conceptions about the occurrence of geologic events at tectonic plate boundaries[2].

(1) Students' conceptions about the nature and movement of tectonic plates

Interviews with students identified seven alternative conceptions about the nature and movement of tectonic plates (Table 4.2). The most common alternative conception held by students was that tectonic plates are underground and are not exposed at the Earth's surface. Often, students thought that tectonic plates are located deep below Earth's crust. The following excerpt from one interview transcript indicates a typical response when students were questioned about their understanding of the nature of tectonic plates:

Researcher	Can you explain to me in your own words what you think a tectonic plate is?
John	A layer of, like, I'm not sure, molten rock maybe? It sits slightly under the surface.

[2] Additional detail about data generation and analysis, including the development of these themes, can be found in Mills, Tomas, and Lewthwaite, 2017.

Another common alternative conception identified in this section concerned the movement of tectonic plates; only one student correctly identified that convection in the mantle is the most commonly accepted cause of tectonic plate movement. These alternative conceptions were not shared between students, however, and students' ideas about the possible driving force of plate movement were varied. Two students believed that gravity somehow caused tectonic plates to move, but neither student could explain how this occurred. For example:

Researcher	You've mentioned that they [*i.e., tectonic plates*] move. Do you know what causes tectonic plates to move?
Leanne	Um::: gravity.
Researcher	And how do you think that works?
Leanne	Well, the pull of something. I don't know exactly.

Two students also believed that tectonic plates move due to Earth's movement. One student thought that Earth's orbit around the sun caused tectonic plates to move, while another explained that Earth's spin on its axis caused tectonic plates to move. For example, "I think it's [*i.e., tectonic plate movement*] to do with the way the Earth moves. The spin it's got affects the plates and which way they move" (Mick). Some students thought that tectonic plates move due to earthquakes or other natural disasters. John, for example, explained, "Um::: generally it is natural disasters and stuff like earthquakes ((pause)). I think that's all". Other reasons offered by students to explain why tectonic plates move were: ocean currents pushing against tectonic plates; bubbles produced by magma boiling in Earth's mantle; and the expansion of tectonic plates.

Table 4.2
Students' alternative conceptions about the nature and movement of tectonic plates

Alternative conceptions	Frequency (*N*=21)
Tectonic plates are underground; they are not exposed at Earth's surface	15
Earth's movement in space causes tectonic plates to move	2
Earthquakes and other natural disasters cause tectonic plates to move	2
Gravity causes tectonic plates to move	2
Tectonic plates expand, which causes them to move	1
Magma boils in Earth's mantle and the bubbles cause tectonic plates to move	1
Ocean currents cause tectonic plates to move	1

(2) Students' conceptions about tectonic plate boundaries

Students held a range of beliefs about the nature of tectonic plate boundaries. Four alternative conceptions arose from interviews with students (Table 4.3). Three students thought that tectonic plate boundaries are located at the edges of countries or entire continents. For example:

Researcher	This is a satellite photograph of the Andes, which is a mountain range in South America. Is this a tectonic plate boundary?
Angela	Yes, because it's bordering the ocean.
Researcher	Do all plate boundaries border the ocean?
Angela	Yes. It's the edge of the country, or continent, or whatever you call it.

One student thought that tectonic plate boundaries were located at the equator: "… tectonic plate boundaries are located in those areas where… They are not usually directly on the equator, they're usually around the equator, I'm pretty sure" (Lisa).

Students were particularly confused about interactions between tectonic plates; specifically, processes that occur at an oceanic-continental convergent plate boundary. No student could identify that the difference in density and thickness between oceanic and continental tectonic plate material is the cause of subductions. At interview, more than half the students thought that the size, rate of movement, and/or relative position of a tectonic plate at a convergent plate boundary influenced its interaction with another plate. For instance, when Mick was shown the same satellite photograph of the Andes, he thought that it represented a tectonic plate boundary in which the smaller tectonic plate was pushed upward to form a mountain range: "Yeah I do believe that one of them, I believe it was that side ((points)), was smaller than the other and pushed itself up and created the mountains all the way across." The same student also believed that the relative position of a tectonic plate influenced the subduction process at an oceanic-continental convergent plate boundary:

Researcher	Do you think it's just the size of the tectonic plate that influences whether it goes above or below?
Mick	Also the position it's in. Because this side might be bigger ((points)) but the other side could just be higher so it just pushed itself over.

Table 4.3
Students' alternative conceptions about tectonic plate boundaries

Alternative conceptions	Frequency (*N*=21)
When two tectonic plates push together the size, speed, and/or relative position of the plates determines how they interact	12
Tectonic plate boundaries are located at the edge of countries	3
When two tectonic plates move apart an empty gap forms between them	1
Tectonic plate boundaries are located at the equator	1

(3) Students' conceptions about geological events at tectonic plate boundaries

Students' conceptions in this category were about the occurrence of geological events at tectonic plate boundaries: the formation of mountains, the formation of volcanoes and the cause of earthquakes. Alternative conceptions about landform formation were most widespread (Table 4.4). The data pertaining to each of these geological events is presented below.

A common idea was that mountains are only formed when the edge of one tectonic plate is pushed upward. Five students explained that this happened when continental plate material is at the edge of both tectonic plates, such at the boundary between the Indian and Eurasian plates where the Himalayas formed. For example:

Nicole	The way that mountains are formed are when two plates push together and eventually they'll just be pushing and pushing and pushing until one sort of pops over and then that can sometimes create a volcano, a mountain, and so forth.
Researcher	So how do you think these mountains were formed ((points to Himalayas))?
Nicole	By tectonic plates pushing together and one, sort of… Just pushing together and one going up.

One student thought that mountains are only formed when the edges of two tectonic plates are pushed upward: "Well I'm thinking that they [the tectonic plates] have collided together and both of them have gone up because that's how mountains are formed" (Mick). Other incorrect ideas were: mountains are formed when pieces of rock pile up; mountains are formed by wind erosion; and all mountains are volcanoes.

The most common alternative conception about the formation of volcanoes, held by three students at interview, was that volcanoes are located in places that have a high temperature, like at the equator. Two students at interview thought that volcanoes are formed when two tectonic plates that have continental plate material at their edge are both pushed upward. Also, 11 students incorrectly understood the cause of earthquakes at interview, believing that earthquakes occur when two tectonic plates crash together at a convergent plate boundary.

Table 4.4
Students' alternative conceptions about the occurrence of geological events at tectonic plate boundaries, including the formation of landforms

Alternative conceptions	Frequency (N=21)
Earthquakes occur when the edges of two tectonic plates suddenly crash together	11
Mountains are only formed when the edge of one tectonic plate is pushed upward	5
All mountains are volcanoes	3
Volcanoes are located in places that have high temperatures, like near the equator	3
When two tectonic plates push together and both plates have continental plate material at their edge, both plates are pushed upward to form a volcano	2
A canyon is formed when two continental plates push together	2
A trench is formed when two oceanic plates move apart	2
When two tectonic plates push together and continental material is at the edge of both plates, one plate is pushed upward to form mountains	2
A trench is formed when the edges of two oceanic plates are pushed upward	1
Mountains are formed by wind erosion	1
Mountains are only formed when the edges of two tectonic plates are pushed upward	1
Mountains form by pieces of rock piling up	1

4.2.3 Developing and validating the instrument

An initial nine-item test instrument was developed. The first tier of each item on the test was a multiple-choice content question and the second tier was a set of possible reasons for the answer given. The reasons consisted of the correct answer and several identified alternative conceptions from student interviews. For instance, in Figure 4.3, students' alternative conceptions about the movement of tectonic of plates that arose at interview (see Table 4.2) have been used.

Question 5

What causes Earth’s tectonic plates to move?

A. Gravity
B. Heat
C. Earth’s movement in space
D. Ocean currents

The reason for my answer is because:

1. Earth’s spin on its axis causes tectonic plates to move
2. Molten rock in Earth’s mantle boils and the bubbles cause tectonic plates to move
3. Molten rock in Earth’s mantle rises and falls creating convention currents that cause tectonic plates to move
4. Earth’s oceans push against continents and cause tectonic plates to move

Figure 4.3. An example item from the GeoQuiz.

The trustworthiness of the test instrument was established in multiple ways. First, as identified earlier, a panel of experts was consulted throughout the entire development process, especially when interpreting the school’s enactment of the curriculum, in order to write propositional knowledge statements to be tested. Second, a specification grid was designed to ensure that the test instrument fairly covers the propositional knowledge statements and the concepts underlying the topic (Table 4.5). Finally, Cronbach’s alpha coefficient was calculated as 0.53, which is higher than the 0.50 threshold proposed for multiple-choice tests (Nunally, 1978).

Table 4.5
Specification grid showing the propositional knowledge statements addressed by each of the GeoQuiz items

Item	Knowledge statements
1	(2), 4
2	(2), (4), 10, 12
3	(2), (4), 10, 11
4	(1), 2
5	(1), 5
6	13, 14, 16
7	(2), (4), 10, 11
8	(2), (4), 6, 7, (17)
9	(2), (4), 20

Note: Numbers refer to knowledge statements found in Table 4.1. Numbers in parentheses indicate that the item is addressing knowledge statements implicitly.

4.4 The Development of the SILS Survey

The SILS survey is a Likert-style questionnaire that was administered to all students before and after their participation in the research project, in order to investigate the relationship between their interest and conceptual change. The survey was adapted from two pre-existing instruments. The sections that follow describe the conceptualisation of interest that was adopted in the current study and how it was measured by the survey; the adaptations that were made to the original instruments; and the reliability and validity checks that were carried out to ensure the trustworthiness of the instrument.

4.4.1 Conceptual origin and adaptations

The first step in desiging the questionnaire for the current study was to conceptualise and operationalise the interest construct. The term ‘interest’ is used in different ways in science education literature. In a recent review, Krapp and Prenzel (2011) explain that interest can be theorised as a relationship between a person and an object (e.g., a topic, subject discipline or idea). The person-object relationship is characterised by cognitive components, such as a readiness to acquire new discipline-specific knowledge, and emotional components, such as an individual’s feelings and values (Hidi & Renninger, 2006; Schiefele, 2009).

Interest can be examined on four different levels (Figure 4.4). Interest can be caused by an already existing dispositional (individual) interest, or may be caused by external (situational) factors (Krapp & Prenzel, 2011). Situational interest can be further broken down into aspects of a context that catch an individual's interest and hold an individual's interest. These two constructs will be referred to as triggered-SI and maintained-SI, respectively, in line with how they have been used in affective conceptual change research (Linnenbrink-Garcia et al., 2010). In a classroom setting, triggered-SI arouses students' affective experiences, so that they actively engage with learning material. On the other hand, "maintained-SI is a more involved, deeper form of situational interest in which individuals begin to forge a meaningful connection with the … material and realise its … significance" (Linnenbrink-Garcia et al., 2010, p. 2).

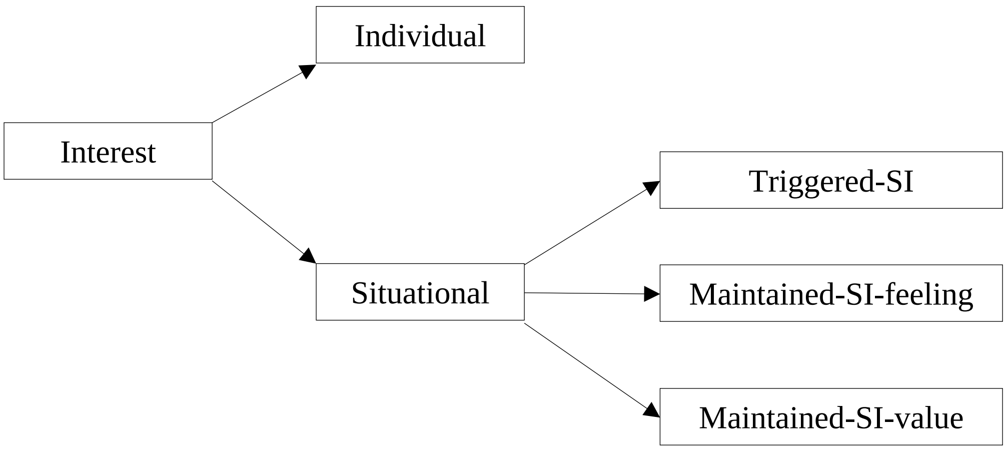

Figure 4.4. Conceptualisation of interest adopted in the current study.

Maintained-SI can be broken down further into two components. Feeling-related components (i.e., maintained-SI-feeling) characterise individuals' affective experiences while engaging with domain content. Value-related components (i.e., maintained-SI-value) emerge as individuals come to believe a domain is important and meaningful (Linnenbrink-Garicia et al., 2010). Although conceptually distinct, it has been theorised that situational interest can evolve into individual interest over time (Hidi & Renninger, 2006). This transformation may occur as an individual views given content and contexts as enjoyable and meaningful, and seeks out opportunities to acquire new discipline-specific knowledge.

Enjoyment is an affective variable that has been given considerable attention alongside interest in the literature, particularly because both have been shown to contribute to student learning and achievement (Ainley & Hidi, 2014). While interest can be defined as feeling engrossed with, or abosrbed in, an activity, enjoyment can be defined as feeling satistifed with, or pleased about, one's participation in an activity (Ainley & Hidi, 2014; Izard, 1977). While interest and enjoyment are generally referred to as being complementary (Ainley & Hidi, 2014), there is no consensus in the literature as to whether they overlap or are distinct concepts. While some scholars have described the relationship between interest and enjoyment as intimately related and reciprocal (Ainley & Hidi, 2014; Izard, 2007, 2009), others assert that these constructs are unique variables that may occur independently of each other (Fredrickson, 2001; Hidi, 2006). Given the recommendation that instrumentation designed to measure interest should include an enjoyment component (Ainley & Hidi, 2014), it was decided that a subscale that measures students' enjoyment learning about Earth science would be included in the survey instrument.

Keeping this conceptualisation of both interest and enjoyment in mind, the SILS survey was developed. The survey consists of 24 items within five subscales that measures aspects of students' individual and situational interest: (1) individual interest in learning about science; (2) enjoyment learning about Earth science; (3) triggered-SI; (4) maintained-SI-feeling; and (5) maintained-SI-value (Table 4.6). The SILS survey was adapted from two existing instruments: the *PISA Student Questionnaire* (OECD, 2006) and the *Situational Interest Survey* (Linnenbrink-Garcia et al., 2010), both of which have been rigorously validated.

Table 4.6
Subscales and items of the SILS survey

Subscale	Item no.	Item
1. Individual interest learning science.	1a	Topics in physics.
	1b	Topics in chemistry.
	1c	The biology of plants.
	1d	Human biology.
	1e	Topics in astronomy.
	1f	Topics in geology.
	1g	Ways scientists design experiments.
2. Enjoyment learning Earth science.	2a	I generally have fun when I am learning Earth science topics.
	2b	I like reading about Earth science.
	2c	I am happy doing Earth science problems.
	2d	I am interested in learning about Earth science.
3. Triggered-SI.	3a	My science teacher is exciting.
	3b	When we do science, my teacher does things that grab my attention.
	3c	My science class is often entertaining.
	3d	My science class is so exciting it’s easy to pay attention.
4. Maintained-SI-feeling.	4a	What we are learning in science is fascinating to me.
	4b	I am excited about what we are learning in science.
	4c	I like what we are learning in science.
	4d	I find the science we do in class interesting.
5. Maintained-SI-value.	5a	What we are studying in science is useful for me to know.
	5b	The things that we are studying in science are important to me.
	5c	What we are learning in science can be applied to real life.
	5d	We are learning valuable things in science.

Subscales 1 and 2 of the survey were taken, or adapted from, Questions 16 and 21 in Section 3 of the PISA questionnaire, *Your Views on Science*. Items belonging to Subscale 1 appear as they do in the PISA questionnaire, as they examine students’ general interest in learning about science. The items in Subscale 2 originally examined students’ cognitive-epistemic (wanting to know more) and emotional (enjoyment) perspectives of science. In the survey, these were adapted slightly to refer to the Earth science discipline, rather than general science. For instance, Item 2a was changed from *'I generally have fun when I am learning science topics'* to *'I generally have fun when I am learning Earth science topics'*.

Subscales 3, 4 and 5 were adapted from the *Situational Interest Survey* (Linnenbrink-Garcia et al., 2010). Items 3a-d measure triggered-SI, Items 4a-d measure maintained-SI-feeling, and Items 5a-d measure maintained-SI-value. The original survey was adapted slightly to make the items specific to the context of the current study. First, this subscale was prefaced with, *Think about your experiences this term while answering the questions below*. Second, wording in the original survey items that ask students to consider their interest in *Maths* was removed and replaced with *Science*. For example, Item 3a was changed from *'This year, my Maths class is often entertaining'* to *'My science class is often entertaining'*. Third, the survey was adapted from a five-point Likert-style scale ranging from 1 (*not true at all*) to 5 (*very true*) to a four-point scale ranging from 1 (*strongly disagree*) to 4 (*strongly agree*). This was done to achieve consistency between the five subscales.

Students responded to each item on the SILS survey using a four-point scale. These responses were scored on a scale of 1-4, so that higher scores represented more positive responses (Table 4.7).

Table 4.7
The scoring of students' responses applied in the analysis of the SILS survey

Subscale	Scoring			
	4	3	2	1
1	High interest	Medium interest	Low interest	No interest
2	Strongly agree	Agree	Disagree	Strongly disagree
3	Strongly agree	Agree	Disagree	Strongly disagree
4	Strongly agree	Agree	Disagree	Strongly disagree
5	Strongly agree	Agree	Disagree	Strongly disagree

4.4.2 Instrument reliability and validity

Estimates of reliability are essential to consider when developing an instrument, and can be achieved via four methods: test-retest, parallel forms, internal consistency and inter-rater reliability (Hubley & Zumbo, 1996). The most appropriate method depends on the nature of the instrument. In the current study, establishing the internal consistency of the survey's subscales was deemed most appropriate. The other methods were discounted with reason. Test-retest reliability was not appropriate as it was anticipated that the project would impact students' interest in learning science, and therefore a change in students' responses was expected; the creation of an alternative form of the survey was a time-consuming and impractical option, and unnecessary considering the survey's conceptual original is very closely related to the *2006 PISA Student Questionnaire* (OECD, 2006) and the *Situational Interest Survey* (Linnenbrink-Garcia et al., 2010); and inter-rater reliability was not appropriate as the SILS survey is a self-report measure.

The SILS survey was found to be a reliable instrument to measure students' individual and situational interest in the current research project. The internal consistency of each of the subscales at pretest was adequate, as Cronbach's α was $\geq .70$ (Hinkin, 1995). Cronbach's α for the adapted subscales also corresponded favorably with the international benchmarks established by PISA and Linnenbrink-Garcia et al. (2010), as shown in Table 4.8.

Any further validation of the SILS survey was deemed unnecessary, as it is an amalgamation of two already validated instruments and only very minor adaptations were made (i.e., only one word in each item was changed). In further support of this decision, Linnenbrink-Garcia et al. (2010) present a full confirmatory factor analysis that identifies the three-factor structure of the *Situational Interest Survey* to be robust across different educational contexts.

Table 4.8
Comparison of Cronbach's α for the original and adapted subscales used in the SILS survey

	Subscales	Number of items	Cronbach's α reliability		
			This project (*N*=95)	PISA 2006 (*N*=500)	SIS* (*N*=236)
1	Individual interest learning science	7	.74	.87	-
2	Enjoyment learning Earth science	5	.86	.94	-
3	Triggered-SI	4	.76	-	.86
4	Maintained-SI-feeling	4	.90	-	.92
5	Maintained-SI-value	4	.85	-	.88

Note: Two measures of internal consistency (Cronbach's α) are presented for each subscale. Results are from this project (calculated at pretest) and either the 2006 round of PISA testing (calculated with weighted national samples from Australia) or from Linnenbrink-Garcia et al. (2010). *SIS stands for *Situational Interest Survey*.

4.5 Chapter Summary

This chapter has detailed the development and validation of the GeoQuiz and the SILS survey. While the GeoQuiz was used to diagnose students' alternative conceptions at both pretest and posttest, the SILS survey was used to measure students' individual and situational interest generated by constructing a slowmation. The development of the GeoQuiz involved determining the scope of the relevant unit of work, *'Changing Earth'* (DETE, 2014a), and researching students' alternative conceptions about the underlying concepts. Once it had become apparent that students' alternative conceptions most commonly concerned the formation of landforms at tectonic plate boundaries, and it was decided that this would be the focus of the intervention, an iteration of the GeoQuiz specific to this topic was developed and refined. The final iteration was validated by a panel of experts who agreed that the test was scientifically accurate and tested fairly the concepts being taught. The development of the SILS survey involved the amalgamation of items, adapted as necessary, from the *PISA Student Questionnaire* (OECD, 2006) and the *Situational Interest Survey* (Linnenbrink-Garcia et al., 2010). Both the GeoQuiz and the SILS survey were found to be reliable and valid instruments suitable for use in the current study. In the next chapter, the quantitative results of the application of these two instruments are presented.

CHAPTER FIVE: QUANTITATIVE RESULTS

5.1 Chapter Introduction

The following chapter presents the quantitative results generated by the application of the GeoQuiz and the SILS survey. Both instruments were administered to all students before and after their participation in the project. The results of these analyses were interpreted to answer the research questions:

(1) Does the process of creating a slowmation representation have a significant effect on students' conceptual change?

(2) Is students' interest, generated by the construction of a slowmation, a significant predictor of conceptual change?

The results of the GeoQuiz are analysed in Section 5.2 and the results of the SILS survey are analysed in Section 5.3. These sections are organised around several sub-questions that were used to interrogate the data. Finally, Section 5.4 provides a summary of the combined analyses.

5.2 GeoQuiz Results

A two-tiered multiple-choice test was employed to determine the effect of creating a slowmation representation on students' conceptual change. The GeoQuiz was administered to four classes of Year 9 students (N=95) before and after their participation in the research project. While two intervention classes participated in the construction of a slowmation (N=52), two comparison classes experienced teaching as usual (N=43). In order to answer the first research question, a series of sub-questions were developed: (1) How did students' conceptions change from pretest to posttest? (2) Was there a significant change in students' overall GeoQuiz scores from pretest to posttest? and (3) Was there a significant change in students' GeoQuiz scores for individual items from pretest to posttest? Both item and statistical analyses were performed to investigate these questions, and the results are presented below.

5.2.1 How did students’ conceptions change from pretest to posttest?

Any change in students’ conceptions from pretest to posttest was initially analysed using descriptive statistics; specifically, the frequency of students with scientific and alternative conceptions at both pretest and posttest was compared within and between both the intervention and comparison conditions. To ease these item analyses, the data were split into questions that concern the nature and movement of tectonic plates (Items 1, 4, 5, and 6) and questions that concern the geological processes that operate at tectonic plate boundaries, including the formation of landforms (Items 2, 3, 7, 8 and 9). Tables 5.1 and 5.2 show the frequencies of students in both the intervention and comparison groups who had scientific and alternative conceptions at pretest and posttest. In line with how other researchers have analysed the results of two-tiered multiple-choice test instruments (as outlined in Chapter 3), responses were considered to be an alternative conception if they were held by more than 10 per cent of students.

A detailed review of this analysis is presented in Sections 5.2.1.1 and 5.2.1.2. Overall, the results indicate that prior to participating in the research project, a moderate proportion of students in both the intervention and comparison groups had alternative conceptions about plate tectonics. Students’ alternative conceptions most commonly concerned the occurrence of geologic events and the formation of landforms at tectonic plate boundaries. Both condition groups (intervention and comparison) generally demonstrated an increase in the number of students with scientific conceptions and a decrease in the number of students with alternative conceptions, from pretest to posttest. Question 3 and Question 8 were exceptions; the number of students in both the intervention and comparison groups with scientific conceptions decreased from pretest to posttest.

5.2.1.1 Students’ conceptions about the nature and movement of tectonic plates

Item 1 required students to identify a tectonic plate boundary on a map (Table 5.1). At pretest, the majority of students selected the correct reason choice by indicating that tectonic plate boundaries occur where two tectonic plates meet. Sixty-four per cent of students in the intervention group and 33 per cent of students in the comparison group had this belief. Some students, however, believed that tectonic plate boundaries align with the edges of the continents. Nineteen per cent of students in the intervention group and 28 per cent of students in the comparison group held this belief. Twenty-six per cent of students in the comparison group believed that tectonic plate boundaries are found at the equator. After instruction, at posttest, more students had a scientific understanding and fewer students had alternative conceptions. The proportion of students who selected the correct reason choice increased to 75 per cent in the intervention group and 63 per cent in the comparison group; an increase of 11 per cent and 30 per cent for the intervention and comparison groups, respectively (Table 5.2). While the number of students in the intervention group who thought that tectonic plate boundaries are located along the edges of continents remained the same (19 per cent), the number of students in the comparison group with this belief decreased to 19 per cent. The number of students who believed that tectonic plate boundaries are found at the equator decreased to nine per cent.

Item 4 examined students' understanding of the nature of tectonic plates (Table 5.1). Prior to their participation in the research project, most students correctly indicated that the outer layer of Earth, including the continents and the ocean floor, consists of tectonic plates. Sixty per cent of students in the intervention group and 51 per cent of students in the comparison group held this belief. A considerable proportion, however, believed that tectonic plates are located deep within the Earth and are not exposed at the surface. Thirty-nine per cent of students in the intervention group and 42 per cent of students in the comparison group held this belief. Having participated in one of the conditions – intervention or comparison – equal or more students had a scientific conception and fewer students had an alternative conception. Sixty per cent of students in the intervention group and 67 per cent of students in the comparison group had a scientific conception, and 33 per cent of students in both the intervention and comparison groups retained an alternative conception. Therefore, the number of students that had a scientific conception after constructing a slowmation remained the same from pretest to posttest, whereas the number of students that held a scientific conception after experiencing teaching as usual increased by 16 per cent (Table 5.2). A moderate proportion of students retained their alternative conception about the location of tectonic plates within Earth's internal structure, which suggests that comprehending and differentiating between the compositional and mechanical layers of the Earth was a difficult task for students.

Table 5.1
Students' alternative conceptions about the nature and movement of tectonic plates, as identified by the GeoQuiz

Item	Reason choice	Response scores* Intervention (*N*=52) Pretest	Posttest	Comparison (*N*=43) Pretest	Posttest
1	Tectonic plate boundaries are found at the edges of continents	19.2%	19.2%	27.9%	18.6%
	Tectonic plate boundaries are found at the equator	3.8%	0%	25.6%	9.3%
	Tectonic plate boundaries only occur where continents meet oceans	9.6%	3.8%	3.8%	9.3%
	Tectonic plate boundaries are where two tectonic plates meet	**63.5%**	**75.0%**	**32.7%**	**62.8%**
4	Earth's tectonic plates are located deep within the Earth and are not exposed at the surface	38.5%	32.7%	41.9%	32.6%
	The outer layer of the Earth, including continents and the ocean floor, consists of separate tectonic plates	**60.0%**	**60.0%**	**51.2%**	**67.4%**
5	Earth's spin on its axis causes tectonic plates to move	19.2%	3.8%	39.5%	16.3%
	Molten rock in Earth's mantle boils and the bubbles cause tectonic plates to move	9.6%	9.6%	14.0%	14.0%
	Molten rock in Earth's mantle rises and falls creating convention currents that cause tectonic plates to move	**67.3%**	**75.0%**	**34.9%**	**51.2%**
	Earth's oceans push against continents and cause tectonic plates to move	3.8%	11.5%	9.3%	14.0%
6	**Earth's continents and ocean basins move a few centimeters each year**	**44.2%**	**53.8%**	**37.2%**	**74.4%**
	Earth's continents and ocean basins move a few centimeters over hundreds of years	38.5%	21.2%	30.2%	11.6%
	Earth's continents and ocean basins move a few centimeters over millions of years	13.5%	23.1%	18.6%	11.6%
	The layer beneath Earth's plates moves very rapidly	0%	0%	7.0%	2.3%

*Note: Scientifically accurate responses are in bold font for ease of reference. The response scores do not always total 100 per cent as some students opted to write their own reason choice.

Table 5.2

The change in students with scientific reasoning about the nature and movement of tectonic plates, from pretest to posttest

		Change in response scores	
Item	Scientific reason choice	Intervention	Comparison
1	Tectonic plate boundaries are where two tectonic plates meet	+11%	+30%
4	The outer layer of the Earth, including continents and the ocean floor, consists of separate tectonic plates	0%	+16%
5	Molten rock in Earth's mantle rises and falls creating convention currents that cause tectonic plates to move	+8%	+16%
6	Earth's continents and ocean basins move a few centimeters each year	+10%	+37%

Note: The condition (intervention or comparison) with the greatest gain in students with scientific conceptions is shaded gray for ease of reference.

Item 5 examined students' understanding of tectonic plate movement (Table 5.1). Students were required to identify heat, and more specifically, convection in the asthenosphere, as the primary driving force behind plate movement. At pretest, 67 per cent of students in the intervention group and 35 per cent of students in the comparison group had an understanding consistent with this scientific viewpoint. There was one pre-instructional alternative conception shared by students in both conditions; specifically, that Earth's spin on its axis causes tectonic plates to move. Nineteen per cent of students in the intervention group held this belief, compared to 40 per cent of students in the comparison group. An additional pre-instructional alternative conception arose from students in the comparison group only. Fourteen per cent of students in this group believed that molten rock in the asthenosphere boils and the bubbles cause tectonic plates to move. At posttest, 75 per cent per cent of students in the intervention group and 51 per cent of students in the comparison group had a scientific conception. Both conditions, then, led to an increase in the number of students with a scientific conception (Table 5.2). The belief that Earth's spin on its axis causes tectonic plates to move decreased considerably among students in both conditions. Only four per cent of students in the intervention group and 16 per cent of students in the comparison group held this belief after instruction. The proportion of students in the comparison group that believed boiling molten rock causes plate movement remained unchanged. Notably, after their participation in the project, more students in both the intervention and comparison conditions thought that Earth's oceans push against continents and cause tectonic plates to move. The number of students in the intervention group with this belief increased from four per cent at pretest to 12 per cent at posttest, and the number of students in the comparison group with this belief increased from nine per cent at pretest to 14 per cent at posttest.

Item 6 elicited students' conceptions about the movement of tectonic plates over time (Table 5.1). Prior to any formal instruction, many students knew that Earth's continents and ocean basins move a few centimeters each year. Forty-four per cent of students in the intervention group and 37 per cent of students in the comparison group held this belief. Nevertheless, most students had an alternative conception about plate movement. Fifty-two per cent of students in the treatment group and 49 per cent of students in the comparison group thought that tectonic plates move a few centimeters over either hundreds or millions of years. After instruction, 54 per cent of students in the intervention group and 74 per cent of students in the comparison group selected the correct reason choice; an increase of 10 per cent and 37 per cent for the intervention and comparison groups, respectively (Table 5.2). The proportion of students who had an alternative conception at posttest decreased. Forty-four per cent of students in the intervention group and 23 per cent of students in the comparison group retained their belief that Earth's tectonic plates move a few centimeters over either hundreds or millions of years.

5.2.1.2 Students' conceptions about the geological processes that occur at tectonic plate boundaries, including the formation of landforms

Students' pre-instructional alternative conceptions about the formation of landforms at tectonic plate boundaries were particularly widespread. Item 2 required students to identify on a map a tectonic plate boundary where a volcano was likely to occur (Table 5.3). Most students recognised that a volcano forms at a tectonic plate boundary when two plates push together. At pretest, only 19 per cent of students in both the intervention and comparison groups knew that when an oceanic tectonic plate and a continental tectonic plate push together, the oceanic plate material is pushed downward and melts to form a volcano. The remaining students thought that when two continental tectonic plates push together, both plates are pushed upward to form volcanoes. Fifty-four per cent of students in the intervention group and 65 per cent of students in the comparison group held this belief. Some students also thought that volcanoes are exclusively located in places that have high temperatures, like at the equator. Fourteen per cent of students in both the intervention and comparison groups held this belief. At posttest, there was an increase in students with a scientific conception, especially for students in the intervention group (Table 5.4). Forty per cent could identify an oceanic-continental convergent plate boundary on a map and understand that the subduction of oceanic lithosphere causes volcanoes. In contrast, 28 per cent of students in the comparison group were capable of this. There was generally a decrease in the number of students with alternative conceptions across both the intervention and comparison groups.

Item 3 concerned the formation of mountains at tectonic plate boundaries (Table 5.3). Again, at pretest, most students recognised that a mountain forms when two tectonic plates push together. Thirty-nine per cent of students in the intervention group and 26 per cent of students in the comparison group had correct scientific reasoning at pretest. A considerable proportion of students, however, believed that the formation of mountains occurs exclusively at continental-continental convergent plate boundaries, where the edges of both tectonic plates are pushed upward. These students did not recognise that mountains also form at oceanic-continental convergent plate boundaries, where oceanic lithosphere is subducted. Forty-eight per cent of students in the intervention group and 47 per cent of students in the comparison group had this pre-instructional alternative conception. Some students believed the opposite to be true, that mountains form exclusively at an oceanic-continental convergent plate boundary. Twelve per cent of students in the intervention group and 23 per cent of students in the comparison group held this belief.

Table 5.3

Students' alternative conceptions about geological processes that operate at tectonic plate boundaries, as identified by the GeoQuiz

Item	Reason choice	Response scores*			
		Intervention (*N*=52)		Comparison (*N*=43)	
		Pretest	Posttest	Pretest	Posttest
2	Volcanoes are located in places that have a high temperature, like at the equator	13.5%	11.5%	14.0%	18.6%
	When two continental tectonic plates push together, both plates are pushed upward to form volcanoes	53.8%	40.4%	65.1%	46.5%
	When an oceanic tectonic plate and a continental tectonic plate push together, the oceanic plate material is pushed downward and melts to form volcanoes*	**19.2%**	**40.4%**	**18.6%**	**27.9%**
	There is a mountain range located here, and all mountains are volcanoes	1.9%	3.8%	0%	4.7%
3	Mountains are formed when the edges of two tectonic plates are pushed upward	48.1%	63.5%	46.5%	39.5%
	Mountains are formed when the edge of one tectonic plate is pushed downward, and one tectonic plate is pushed upward	11.5%	11.5%	23.3%	34.9%
	Mountains are formed when both 1 and 2 occur*	**38.5%**	**25.0%**	**25.6%**	**23.3%**
	Mountains are formed when pieces of rock pile up	1.9%	0%	4.7%	2.3%
7	When two tectonic plates push together for millions of years, the larger tectonic plate is pushed upward	25.0%	21.2%	27.9%	32.6%
	When two tectonic plates push together for millions of years, the faster moving tectonic plate is pushed upward	11.5%	7.7%	30.2%	20.9%
	When two tectonic plates push together for millions of years, the more buoyant tectonic plate is pushed upward*	**34.6%**	**57.7%**	**23.3%**	**32.6%**
	When two tectonic plates push together for millions of years, the tectonic plate that is positioned the highest is pushed upward	26.9%	11.5%	18.6%	14.0%
8	When two tectonic plates separate, an empty gap forms between them	42.3%	46.2%	30.2%	39.5%
	When two tectonic plates separate, loose rock fills the gap that forms between them	13.5%	7.7%	30.2%	25.6%
	The continents are separated and oceanic crust material is formed between them*	**26.9%**	**23.1%**	**18.6%**	**11.6%**
	A trench forms when oceanic crust material separates	17.3%	19.2%	18.6%	20.9%
9	Earthquakes occur at plate boundaries when two tectonic plates crash together	21.2%	11.5%	44.2%	9.3%
	Earthquakes occur at plate boundaries when two tectonic plates suddenly move apart	25.0%	11.5%	16.3%	7.0%
	Earthquakes occur along breaks in rock where one side moves	**3.8%**	**17.3%**	**7.0%**	**18.6%**
	Earthquakes occur when two tectonic plates rub together	48.1%	57.7%	32.6%	62.8%

*Note: Scientifically accurate responses are in bold font for ease of reference. The response scores do not always total 100 per cent as some students opted to write their own reason choice.

Table 5.4

The change in students with scientific reasoning about the formation of landforms at tectonic plate boundaries, from pretest to posttest

		Change in response scores	
Item	Scientific reason choice	Intervention	Comparison
2	When an oceanic tectonic plate and a continental tectonic plate push together, the oceanic plate material is pushed downward and melts to form volcanoes	+21%	+9%
3	Mountains are formed when both 1 and 2 occur	-14%	-3%
7	When two tectonic plates push together for millions of years, the more buoyant tectonic plate is pushed upward	+23%	+10%
8	The continents are separated and oceanic crust material is formed between them	-4%	-7%
9	Earthquakes occur along breaks in rock where one side moves	+13%	+12%

Note: The condition (intervention or comparison) with the greatest gain in students with scientific conceptions is shaded gray for ease of reference.

The proportion of students in both conditions with correct scientific reasoning at posttest decreased, which suggests that students remained confused about the formation of mountains (Table 5.4). Most students across both conditions believed that mountains are exclusively formed when the edges of two tectonic plates are pushed upward. Sixty-four per cent of students in the intervention group and 40 per cent of students in the comparison group held this belief. This unusual finding may be due to students not selecting the *most correct* reason choice as their answer.

The different composition of oceanic and continental lithosphere is key to students' understanding of the geological processes that operate at tectonic plate boundaries. Item 7 revealed students' conceptions about how tectonic plates interact at an oceanic-continental convergent plate boundary (Table 5.3). Prior to instruction, 35 per cent of students in the intervention group and 23 per cent of students in the comparison group correctly identified that the difference in density and thickness between oceanic and continental plate material means that continental lithosphere is more buoyant, and is therefore pushed upward. A range of alternative conceptions was also identified. Most notably, students indicated that when two tectonic plates push together the size, speed, and/or relative position of the plates determines how they interact. Sixty-three per cent of students in the intervention group and 77 per cent of students in the comparison group had one of these incorrect beliefs. After participating in their respective instruction, 58 per cent per cent of students in the intervention group and 33 per cent of students in the comparison group correctly chose a scientifically accurate reason choice; an increase of 23 per cent and 10 per cent for the intervention and comparison groups, respectively (Table 5.4). The proportion of students with alternative conceptions decreased.

Item 8 examined students' ideas about divergent plate boundaries, and more specifically, that sea-floor spreading that occurs at a mid-ocean ridge (Table 5.3). At pretest, a moderate proportion of students correctly identified that new oceanic crust forms at a mid-ocean ridge. Twenty-seven per cent of students in the intervention group and 19 per cent of students in the comparison group had this belief. Students also had pre-instructional alternative conceptions. The most prevalent alternative conception was that a gap remains when tectonic plates move apart. Forty-two per cent of students in the intervention group and 30 per cent of students in the comparison group held this belief. The other alternative conceptions that were identified are that loose rock fills the gap that forms between two tectonic plates when they separate, and a trench forms when two tectonic plates separate. It appears that students found the notion of sea-floor spreading difficult to comprehend, as the number of students with a scientific conception at posttest decreased to 23 per cent in the intervention group and 12 per cent in the comparison group. The proportion of students with alternative conceptions increased. Students' difficulty understanding the geological processes that operate at a divergent plate boundary, and representing these processes using three-dimensional models, is given further consideration in the next chapter.

Few students demonstrated a scientific understanding about how earthquakes occur in response to Item 9 (Table 5.3). This was true at both pretest and posttest. Before instruction, only four per cent of students in the intervention group and seven per cent of students in the comparison group knew that earthquakes occur along breaks in a rock, where one side moves relative to the other side. This only marginally increased post-instruction. Seventeen per cent of students in the intervention group and 19 per cent of students in the comparison group selected the correct reason choice. The most popular response for this item was that earthquakes occur when two tectonic plates rub together. Forty-eight per cent of students in the intervention group and 33 per cent of students in the comparison group held this belief at pretest. The proportion of students with this belief increased at posttest to 58 per cent of students in the intervention group and 62 per cent of students in the comparison group. A moderate proportion of students in both groups also believed that earthquakes occur when tectonic plates crash together or suddenly move apart, however fewer students believed this at posttest.

5.2.2 Was there a significant change in students' overall GeoQuiz scores from pretest to posttest?

To investigate whether the process of creating a slowmation representation had a significant effect on students' conceptual change, quantitative analyses of the pretest and posttest GeoQuiz data were performed. A repeated measures analysis of variance (ANOVA) revealed a significant within-subjects effect for time, Wilks's $\Lambda = 0.61$, $F(1, 93) = 59.96$, $p < .001$, partial $\eta^2 = 0.39$, which indicates that students' mean test scores changed from pretest to posttest. A significant between-subjects effect was observed for condition, $F(1, 93) = 13.89$, $p < .001$, partial $\eta^2 = 0.13$, as the treatment and comparison groups had significantly different mean test scores at both pretest and posttest. The critical time*condition interaction was non-significant, however, which indicates that both the intervention and comparison groups' mean test scores changed comparably from pretest to posttest.

Follow-up *t*-tests were conducted to investigate the significant time and condition main effects. Paired-samples *t*-tests revealed a significant improvement in the mean test scores of both groups from pretest to posttest (Table 5.5). Large effect sizes, as measured by Cohen's *d*, were observed in each case, which is unusual for research in educational settings (Tabachnick & Fidell, 2007). Independent-samples *t*-tests showed that the intervention group's test scores were significantly greater than the comparison group's scores at pretest, $t(93) = 3.64$, $p = < .001$, and posttest, $t(93) = 3.08$, $p < .01$.

Table 5.5
Results of the paired samples t-tests, which examined changes in students' GeoQuiz scores from pretest to posttest

	Pretest mean (SD)	Posttest mean (SD)	*t*-Value	df	Sig.	Cohen's *d*
Comparison	9.05 (4.30)	12.28 (4.30)	-4.72	42	.000*	.72
Intervention	12.29 (4.34)	15.08 (4.49)	-6.52	51	.000*	.91

*Significant at the $p < .001$ level (two-tailed).

A supplementary repeated measures ANOVA was carried out to determine if this interpretation of results would remain the same when gender and class teacher were included as additional independent variables. There remained a significant within-subjects effect for time, Wilks's $\Lambda = 0.64$, $F(1, 87) = 49.70$, $p < .001$, partial $\eta^2 = 0.36$, and between-subjects effect for condition, $F(1, 87) = 15.12$, $p < .001$, partial $\eta^2 = 0.15$. There was an additional between-subjects effect for class teacher, $F(1, 87) = 5.90$, $p < .05$, partial $\eta^2 = 0.06$. There was also an additional significant interaction effect between class teacher*condition, $F(1, 87) = 6.45$, $p < .05$, partial $\eta^2 = 0.07$. This suggests that each pair of treatment and comparison classes performed differently over the course of the project. No significant findings were observed for gender. The critical time*condition*teacher and time*condition*gender interactions were non-significant. This suggests that there were no differences in the ways in which boys and girls responded to the project, and that the project was implemented comparably across classes; therefore, the original interpretation of results is valid.

5.2.3 Was there a significant change in students' GeoQuiz scores for individual items from pretest to posttest?

The effect of the intervention on students' scores for individual questions was explored by conducting a repeated measures multivariate analysis of variance (MANOVA). This type of analysis was chosen because it reduces the probability of a Type I error (i.e., the probability of rejecting a null hypothesis when it is true) when multiple dependent variables are being analysed (Green & Salkind, 2005). Overall, a significant main effect was observed for time, Wilks's $\Lambda = 0.48$, $F(9, 85) = 10.20$, $p < .001$, partial $\eta^2 = 0.52$, as students' scores for individual questions changed from pretest to posttest. There was also a significant main effect observed for condition, Wilks's $\Lambda = 0.73$, $F(9, 85) = 3.47$, $p < .001$, partial $\eta^2 = 0.27$, because the treatment and comparison groups had significantly different test scores for individual items at both pretest and posttest. The crucial time*condition interaction was non-significant. This means that there was no significant difference from pretest to posttest between the intervention and comparison groups in their conceptual change at the individual question level.

5.4 SILS Survey Results

Data on students' individual and situational interest were generated using the SILS survey. The survey was administered to all students (*N*=95) immediately before and after the research project. Five dimensions of students' interest were measured on separate subscales. These were: interest in learning science (including an item that measured interest in learning geology topics); enjoyment learning Earth science; triggered-SI; maintained-SI-feeling; and maintained-SI-value. The results of the analyses are organised according to three questions that were used to interrogate the data: (1) Was there a significant change in students' overall SILS survey scores from pretest to posttest? (2) Was there a significant change in students' overall SILS survey scores for interest in learning geology topics from pretest to posttest? and (3) Was students' interest, generated by the project, a significant predictor of their conceptual change? The results pertaining to each of these sub-questions are presented in the sections that follow. Raw data tables for the SILS survey are presented in Appendix F.

5.4.1 Diagnostics and assumptions

Before conducting the analyses, the survey response data were examined for missing values, and the extent to which its distribution met the assumptions of univariate and multivariate analyses (Tabachnick & Fidell, 2007). No cases of missing data or out of range values were found, and all data were normally distributed. An examination of *z* scores with a cut-off of ±3.29 revealed one univariate outlier. Therefore, the analyses presented in this section were conducted twice; once with the data intact and once with the outlier removed. As there was no marked difference in interpretation of the results[3], the outlying datum was included in the analyses that are reported. Homogeneity of variance was tested using Levene's Test of Equality of Error Variances, which revealed that the variances for the variables were equal across groups ($p < .001$), with the exception of the posttest scores for Subscale 4 (i.e., maintained-SI-feeling). As the sample sizes were unequal, homogeneity of covariance was assessed using Box's *M* Test, which showed that the group covariance matrices were equal ($p < .001$). Lastly, tolerance values were high enough to discount multicollinearity or singularity.

5.4.2 Was there a significant change in students' overall SILS survey scores from pretest to posttest?

To examine the change in students' interest from pretest to posttest, a MANOVA was conducted. The independent variables were time (from pretest to posttest) and condition (intervention or comparison), and the dependent variables were students' mean scores on the four interest subscales: individual interest, triggered-SI, maintained-SI-feeling and maintained-SI-value. An alpha level of .05 was adopted for all analyses. Mean scores and standard deviations for each dependent variable by group are presented in Table 5.6.

Table 5.6
A summary of the descriptive statistics for the SILS survey subscales

Variable	Condition	Pretest	Posttest
		Mean (SD)	Mean (SD)
Individual interest	Intervention	2.56 (0.48)	2.77 (0.54)
	Comparison	2.48 (0.62)	2.43 (0.69)
Enjoyment	Intervention	2.67 (0.52)	2.78 (0.68)
	Comparison	2.52 (0.70)	2.52 (0.79)
Triggered-SI	Intervention	2.82 (0.51)	3.06 (0.57)
	Comparison	2.77 (0.55)	2.62 (0.71)
Maintained-SI-feeling	Intervention	2.59 (0.60)	2.89 (0.51)
	Comparison	2.61 (0.84)	2.42 (0.91)
Maintained-SI-value	Intervention	2.68 (0.60)	2.73 (0.60)
	Comparison	2.59 (0.76)	2.49 (0.80)

[3] The only change in the results was that the main effect of condition no was longer significant when the outlier was removed. This was not considered to be a marked change, as it did not relate to the crucial time*condition interaction.

No significant main effect of time was observed. A significant main effect for condition was observed, Wilks's $\Lambda = 0.88$, $F(5, 88) = 2.36$, $p = .046$, partial $\eta^2 = .12$. The crucial time*condition interaction effect was significant, Wilks's $\Lambda = 0.80$, $F(4, 89) = 5.42$, $p = .001$, partial $\eta^2 = .20$, which suggests the intervention and comparison groups performed differently on the survey subscales over the project.

To explore further the critical time*condition interaction for each interest subscale, a series of univariate ANOVAs were conducted. There was no main effect for time for each interest subscale. While there were no main effects for condition on most subscales, there was a significant main effect for condition for triggered situational interest (i.e., Subscale 2), $F(1, 92) = 4.33$, $p = .04$, partial $\eta^2 = .05$. As shown in Table 5.7, there was a significant time*condition interaction for individual interest in learning about science, triggered-SI, and maintained-SI-feeling. There was no significant time*condition interaction for enjoyment learning about Earth science or maintained-SI-value.

Table 5.7
*Results of the univariate analyses, which examined the significant time*condition interaction*

Variable	df	F	Sig.
Individual interest	1	8.41	.005*
Enjoyment	1	0.27	.61
Triggered-SI	1	15.46	.000**
Maintained-SI-feeling	1	13.90	.000**
Maintained-SI-value	1	1.32	.25

*Significant at the $p < .05$ level (two-tailed). ** Significant at the $p < .001$ level (two-tailed).

A series of paired samples *t*-tests were carried out to explore the univariate time*condition interactions (Table 5.8). For the individual interest in learning about science subscale, there was a significant increase in the intervention group's interest level, which was not observed for the comparison group. For the triggered-SI subscale, the intervention group's interest significantly increased, whereas the comparison group's interest significantly decreased. This trend was also observed for the maintained-SI-feeling subscale. Neither groups' enjoyment learning about Earth science or maintained-SI-value changed significantly from pretest to posttest.

A supplementary MANOVA that included teacher and gender as additional independent variables was conducted. The crucial four-way time*condition*gender*teacher interaction was not significant, nor were the three-way time*condition*gender and time*condition*teacher interactions. Therefore, the original results without the additional variables of class teacher and gender were retained.

Table 5.8
Results of the paired samples t-tests, which examined changes in students' interest from pretest to posttest

Variable	Condition	ΔMean	*t*-Value	df	Sig.	Cohen's *d*
Individual interest	Intervention	0.25	-3.48	51	.001*	.49
	Comparison	-0.05	0.79	42	.440	.12
Enjoyment	Intervention	-0.11	-0.90	51	.371	.18
	Comparison	-0.005	-0.03	42	.979	.00
Triggered-SI	Intervention	0.24	-3.24	51	.002*	.46
	Comparison	-0.15	2.38	42	.022*	.39
Maintained-SI-feeling	Intervention	0.29	-2.83	51	.007*	.40
	Comparison	-0.19	2.46	42	.018*	.37
Maintained-SI-value	Intervention	0.05	-0.58	51	.568	.08
	Comparison	-0.10	1.06	42	.294	.17

*Significant at the $p < .05$ level (two-tailed).

5.4.3 Was there a significant change in students' overall SILS survey scores for interest in learning geology topics from pretest to posttest?

A separate repeated measures ANOVA was conducted to investigate how students' interest in geology topics only (i.e., Item 1f only) changed from pretest to posttest. A significant main effect was observed for time, $F(1, 93) = 6.22$, $p < .05$, partial $\eta^2 = 0.63$, and condition, $F(1, 93) = 4.33$, $p < .05$, partial $\eta^2 = 0.48$ A significant interaction effect was observed for time*condition, $F(1, 93) = 2.30$, $p < .05$, partial $\eta^2 = 0.63$. As the main effects observed for time and condition were artifacts of the time*condition interaction, they were not investigated any further. Follow-up paired samples *t*-tests were conducted to investigate the critical time*condition interaction. As shown in Table 5.9, the analyses revealed that the intervention group's interest in learning about geology topics increased significantly more than the comparison group's interest in learning about geology topics, over the course of the research project.

Table 5.9
Results of the paired samples t-tests, which examined changes in students' interest in learning about geology topics, from pretest to posttest

	Pretest mean (SD)	Posttest mean (SD)	*t*-Value	df	Sig.	Cohen's *d*
Comparison	2.30 (0.80)	2.30 (0.91)	0.00	42	1.00	.00
Intervention	2.38 (0.72)	2.83 (0.79)	-3.86	51	.000*	.53

*Significant at the $p < .001$ level (two-tailed).

5.4.4 Was students' interest, generated by the project, a significant predictor of their conceptual change?

To investigate the relationship between students' conceptual change and interest, Pearson correlation coefficients were calculated among the GeoQuiz and SILS survey change scores for students who constructed a slowmation. The results of the correlation analysis show that three types of interest were significantly related to students' conceptual change: individual interest in learning about science, triggered-SI and maintained-SI-feeling (Table 5.10).

A multiple regression analysis was conducted to evaluate how well students' overall interest predicted their conceptual change. Before conducting the analysis, the data were examined for missing data and the extent to which their distribution met the assumptions of a multiple regression analysis (Tabachnick & Fidell, 2007). The data for students' maintained-SI-feeling and maintained-SI-value were slightly skewed. As such, the multiple regression was run twice, once with the data intact and once with three univariate outliers removed (two of which were also multivariate outliers). The removal of the univariate outliers reduced the skewness to an acceptable level. The interpretation of both analyses was identical, and therefore the original analysis with intact data were retained.

Table 5.10
Results of the correlation analysis, which examined relationships between the GeoQuiz and SILS survey change scores, for students who constructed a slowmation

	1	2	3	4	5	6	M	SD
1. GeoQuiz	-						2.79	3.08
2. Individual interest	.29*	-					0.24	0.51
3. Enjoyment	- .08	.09	-					
4. Triggered-SI	.40**	.36**	.09	-			0.24	0.52
5. Maintained-SI-feeling	.38**	.30*	.31*	.65**	-		0.29	0.73
6. Maintained-SI-value	.08	.32*	.24	.37**	.41**	-	0.00	0.75

*Significant at the $p < .05$ level (two-tailed), ** Significant at the $p < .01$ level (two-tailed).

Students' overall change in interest, generated by the project, was a significant predictor of their change in GeoQuiz scores, $F(5, 45) = 3.32$, $p = .023$. The multiple correlation coefficient was .50, indicating that approximately 25 per cent of change in GeoQuiz scores can be accounted for by the linear combination of students' interest scores. Despite this, none of the interest subscales individually predicted students' change in GeoQuiz scores. Overall, this means that students' interest in learning science was significantly greater if they participated in the construction of a slowmation (compared to teaching as usual); and, students' interest was found to be a significant predictor of their conceptual change.

5.5 Chapter Summary

This chapter has presented the results of the quantitative analysis of the test and survey instruments, and, in doing so, answers two of the research questions outlined in Section 5.1. In answering the first research question, it was found that creating a slowmation led to a significant improvement in students' conceptual change; however, a significant improvement was also found for students in the comparison classes. In other words, creating a slowmation was no more effective in bringing about conceptual change than teaching as usual. In answer to the third research question, students' interest in learning science was significantly greater if they participated in the construction of a slowmation, compared to teaching as usual. In addition, students’ interest was found to be a significant predictor of their conceptual change. In the next chapter, the qualitative research findings are presented.

CHAPTER SIX: QUALITATIVE RESULTS

6.1 Chapter Introduction

As outlined in Chapter 3, a sub-sample of students (*N*=19) were audio-recorded while they worked in groups to provide an insight into how the slowmation construction process influenced their conceptual change. Most of these students (*N*=17) also agreed to participate in a post-intervention interview, where they were asked about their experiences and perceptions of making a slowmation. The findings that emerged from the post-intervention interviews were primarily used to gain further insight into the relationship between students' interest and conceptual change, and to triangulate the findings of the SILS survey that were presented in the preceding chapter.

This chapter now presents the qualitative research findings. First, Section 6.2 presents a brief overview of the audio-recording and interview procedures, and their analyses. Second, Section 6.3 presents evidence to support the first key finding that constructing a slowmation had a facilitating influence on students' conceptual change. This occurred in two ways: (1) the teacher identified and corrected students' alternative conceptions; and (2) students attributed their learning, in part, to the feelings of enjoyment aroused by constructing a slowmation. Third, Section 6.4 presents evidence to support the second key finding that despite its merit, constructing a slowmation also raised significant pedagogical issues that appeared to inhibit opportunities for conceptual change to occur. These were: (1) students' preoccupation with the procedural aspects of constructing a slowmation; (2) students' apparent lack of motivation to understand the science content and represent it accurately; (3) students' privileging and bypassing modes of representation; and (4) time constraints. Fourth, to conclude the chapter, a summary of the qualitative research findings is presented in Section 6.5.

6.2 Overview of Audio-Recording and Interview Procedures and Analyses

Students constructed a slowmation across four 70-minute lessons. Six groups of students (*N*=19) were audio-recorded throughout the construction of their slowmation (i.e., three groups of students from each intervention class; Table 6.1). The researcher manually transcribed the audio-recordings, using pseudonyms for students' names. An initial exploratory analysis was carried out, whereby the transcripts were read several times in their entirety to discern what was important in the data and what was not. During this process, any 'codable moments' worthy of attention were highlighted for ease of reference in later analyses, as outlined in Section 3.4.3.2.

Table 6.1
The sub-sample of students who were audio-recorded while they constructed their slowmation in groups

Teacher A	**Teacher B**
Class 1: Intervention	**Class 3: Intervention**
Group 1: Amanda, Melanie and Sam	Group 5: Michael and Will
Group 2: Ellie, Louisa and Jason	Group 6: Trevor, Joe and Zach
Group 3: Joel and Ryan*	Group 7: Kate, Lilly and Sarah
Group 4: Anna, Jackson and Paul*	

*Note: Group 3 was audio-recorded for Lesson 1 only, and Group 4 was audio-recorded for Lessons 2, 3 and 4 only. This was because Joel and Ryan were absent in the subsequent lessons. All other groups were audio-recorded for the full four lessons.

As previously mentioned, the results of these analyses support two key findings about how constructing a slowmation influenced students' learning: (1) constructing a slowmation helped to facilitate students' learning about plate tectonics, and (2) pedagogical issues associated with constructing a slowmation inhibited opportunities for conceptual change to occur. These key findings are suggestive of the complexity of engaging students in the construction of a slowmation in a junior secondary science context. In the following sections, nuanced data that supports and illuminates these findings are presented.

6.3 Key Finding 1: Constructing a Slowmation Facilitated Students' Conceptual Development

As shown by the results of the quantitative analysis of the GeoQuiz data (Chapter 5, Section 4.2.2), students in the intervention classes demonstrated significant improvements in their understanding of plate tectonics. Analysis of the student interview data provided some interesting insight into how constructing a slowmation facilitated students' learning. At the onset of this project, based on existing literature that has examined the efficacy of slowmation in pre-service teacher education contexts, it was expected that constructing a slowmation would facilitate an active, student-centred learning environment, wherein students learned about plate tectonics by producing different representations, discussing their learning with one another and the teacher, and refining their animations. What actually occurred, however, was very different. Instances of conceptual development came about through instruction from the teacher, rather than from the construction process itself. Despite this, the construction process was perceived as particularly memorable for students. At interview, students recalled their enjoyment constructing a slowmation, which they perceived to have enhanced their learning. The evidence that supports these two claims is presented in the subsequent sections.

6.3.1 The teacher identified and/or corrected students' alternative conceptions during the construction process

There were several instances across the audio-recorded lessons where the teacher or researcher (as observer-participant) identified and/or corrected students' alternative conceptions. In the first instance presented here, the researcher corrected one group's misconceived notion of geologic time.

While trying to accurately represent the formation of the Himalayas over time, two group members, Anna and Paul, thought that the mountain range had formed relatively quickly, over hundreds or thousands of years. Their third group member, Jackson, thought that the mountain range had formed over millions of years:

Excerpt 6.1

Paul:	So we've done that one, that one, that one… ((Reading)) "How are these landforms created and how long does the process take?"
Jackson:	It takes millions of years.
Anna:	It probably took, like, 100 years or something.
Jackson:	No, for mountains to form it would take, like, millions of years-

Paul: Thousands.

Anna: It wouldn't take *millions* of years! Otherwise we wouldn't have all the mountains we have today.

Jackson: Well the Earth is billions of years old, so there was plenty of time.

It is obvious from the excerpt above that Anna and Paul do not understand that the formation of a large mountain range, such as the Himalayas, may have taken around 100 million years. Later on in the construction process, the researcher unintentionally corrected the students' misunderstanding. He suggested to this group, "You know what would be cool? If you used a label to show how long this process takes. It would have taken millions of years." Jackson, acknowledging that he was correct despite his group's reluctance to believe him, exclaimed, "Yes! I was right!" In this instance, the researcher inadvertently addressed the students' alternative conception. In this group's final slowmation, the geological time scale was represented accurately, which suggests that as a result of the researcher's comments, the students had a more scientific conception about the timescale on which Earth's geological processes operate.

In another instance, there was confusion between Joe and Zach about the direction of plate movement, and the resulting landforms, at a divergent plate boundary. In Excerpt 6.2, they come to the conclusion that the plates move away from each other and a trench is formed:

Excerpt 6.2

Zach: Joe?

Joe: Yeah?

Zach: Is a divergent plate boundary where they smash together and one goes up and one goes down?

Joe: Um::: yeah. I believe one goes up and one goes down. I think.

Zack: I'll check.

Joe: [Yeah, that's right.]

Zack: OK. They move away and they make a trench.

Joe: Yeah.

This incorrect belief persisted throughout the planning and construction phases. When discussing what to include in their slowmation, Zach suggested that they should “talk about trenches”, while Joe replied, “We’ll explain that the crust pulls away from each other and leaves a trench.” The teacher was again crucial in resolving the students’ confusion. In Excerpt 6.3, when the students begin to manipulate their three-dimensional models, they ask the teacher for help:

Excerpt 6.3

Zach: When two continental ones *[plates]* move apart, does it create a trench?

Teacher: No, not a trench. It creates what’s called a continental rift.

Zach: But-

Teacher: It’s kind of like-

Zach: [Just a gap?]

Teacher: -where the crust thins out and the magma below rises and can erupt onto the surface.

Accepting that a continental rift occurs at a continental divergent plate boundary, the students then turned their attention to representing this landform using their models. This revealed further alternative conceptions about the spatial scale of geological processes such as rifting, that were once again addressed through instruction from the teacher:

Excerpt 6.4

Zach: Do you think we could use this *[two pieces of thick sponge]* and pull it in half and pretend that’s the crack opening? And then we’ll just put magma coming through?

Teacher: Yeah if you want. You need to show what happens there *[in the space that is left from separating the two pieces of sponge]*.

Trevor: Yeah we have to try and decide. Because originally we thought we were going to put the trench in there but now we're not sure.

Teacher: Isn't red *[coloured paper on top of the pieces of sponge]* continental crust? Continental-continental. So this would be a rift basin where you sometimes have eruptions happening. Maybe show the crust in the basin and have some magma coming up. It can't stay as an empty gap.

Zach: Yeah:::

From the two previous exchanges it is evident that Zach had perceived a continental rift as an empty "gap" or "crack" in Earth's lithosphere, rather than a thinning of the lithosphere over tens of kilometers. Therefore, in addition to him incorrectly believing that this process forms a trench, he also had a misunderstanding of the spatial scale of continental rifting. This is further evidenced by Zach's suggestion that a rift can be "joined back together" as the magma that rises to the Earth's surface hardens over time. The teacher explained to Zach that the extension of the lithosphere occurs until it separates, and that by this time the basin that forms is sufficiently deep to be in-filled by the ocean: "It won't fill up with magma. It's more likely to fill up with water and form a rift lake or a new ocean basin." In response, both students appeared to revise their initial understanding of the process. Trevor said, "Ah I see! It's like that!" and Zach said, "… that makes sense."

Ellie and Louisa also struggled to understand the nature of divergent plate boundaries and the landforms that occur at these places. Ellie and Louisa began their research by determining the direction of plate movement. After explicit instruction from the teacher, the students came to know that tectonic plates move apart at a divergent plate boundary:

Excerpt 6.5

Louisa:	Does it *[the lithosphere]* even come back together? I don't understand.
Ellie:	No, it wouldn't… Yeah it would have to because otherwise the tectonic plates would have holes in them.
Louisa:	I guess so. I'll ask.
Louisa:	We were just, um, a bit confused about divergent plate boundaries. We're wondering if they separate and then they come back like *that*, or they come back like *that*?
Teacher:	Neither. They keep separating.

This new information, however, did not fit with their understanding about how volcanoes form in these areas. In Excerpt 6.6, the teacher explains that magma can find its way easily to the Earth's surface through the weakened lithosphere and cause volcanic activity:

Excerpt 6.6:

Ellie:	OK so how does a volcano form if the tectonic plates are separating?
Teacher:	Well, what do *you* think? What's a volcano?
Ellie:	Magma?
Teacher:	Yeah. So if two pieces of lithosphere move apart over hundreds of thousands of years, what's left?
Ellie:	A hole?
Teacher:	And what's going to fill the 'hole'?
Ellie:	Magma?
Teacher:	Yeah.
Ellie:	OK!
Louisa:	[OK!]

The teacher further explains that this can occur on land at a continental rift or on ocean floor at a mid-ocean ridge:

Excerpt 6.7

Teacher:	The types of volcanoes that occur at divergent plate boundaries… Well, it depends. If the plate boundary is beneath the ocean, the process is called sea-floor spreading, and the magma that rises from the asthenosphere ends up forming crust – the ocean floor. OK?
Louisa:	Yep.
Ellie:	[Yep.]
Teacher:	If it's on land you end up with kind of like… What's it called? Um::: a continental rift. And you can have fissure eruptions. That doesn't look like a mountain, like a normal volcano does, it's just where the lithosphere has thinned out and there might be lava on the Earth's surface. Does that make sense?
Ellie:	Yeah! Thank you!

Later, during the construction process, it becomes apparent that Louisa is still confused about the direction of tectonic plate movement at a divergent plate boundary and the subsequent formation of either a continental rift or a mid-ocean ridge. In the following exchange, Excerpt 6.8, Louisa wants to "build up" the lithosphere by pushing two thick sponges "inwards". Louisa thinks that this will represent the formation of a volcano at a divergent plate boundary:

Excerpt 6.8

Louisa:	So cut this *[a thick sponge]* in half and put one here and here to make the volcano? Ellie what are you thinking about? Express your thoughts and feelings! ((Laugh))
Ellie:	Like that. Not folded like that. It's a volcano that forms out of land-

Louisa:	Out of land? ((Laugh))
Ellie:	Out of magma.
Louisa:	Are we going to make it so that there are plate boundaries and build it up? So that it goes inwards sort of?
Ellie:	What? I don't know what you're talking about. No *these* are the plate boundaries. And the plate boundaries spread apart and then magma comes in between them and then it *[the volcano]* forms in the middle of it.
Louisa:	Oh! OK! I don't know how I'm going to () using sponges.
Ellie:	I think you're confused because the plates only go like *this*. They don't go up.
Louisa:	[Yeah I am confused.]

As a result of the explicit instruction from the teacher, it is evident that Ellie had a more scientific conception of divergent plate boundaries. She demonstrated her understanding by explaining to Louisa that, "… the plate boundaries spread apart and then magma comes in between them and *[a volcano]* forms." Louisa, on the other hand, remained confused.

The importance of teacher intervention in helping to identify and modify students' alternative conceptions was highlighted by one identified instance wherein two students' misunderstanding about the formation of mountains and volcanoes persisted throughout the project. In this instance, Michael and Will were researching landforms that occur at a continental-continental convergent plate boundary. They were unable to distinguish between the formation of mountains and volcanoes, as illustrated in the following excerpt:

Excerpt 6.36

Will:	What was the question?
Michael:	((Reading)) "What landforms occur at your plate boundary?"
Will:	Mountains, volcanoes-
Michael:	Are you sure?

Will: Not one hundred per cent. Mountains and volcanoes will occur, I know those.

Will's alternative conception about the formation of these landforms persisted throughout the planning and construction phases, where he suggests his group "… draw the *[continental]* plates moving together and have them turn into a volcano." He reveals his belief that "… the volcano builds and erupts and then it turns into a mountain." This belief, unchallenged by Michael, was retained and represented in the students' final slowmation.

6.3.2 Students found their experience constructing a slowmation enjoyable, which they perceived to enhance their learning

Although the analyses of the SILS survey results (Chapter 5, Section 5.4.2) showed only a marginal increase in students' enjoyment of learning about Earth science topics, students' comments during the post-intervention interviews indicated that the way in which they learnt about this topic in the current study (i.e., through the construction of a slowmation) was indeed enjoyable. Specifically, students noted that they enjoyed the hands-on construction process, and the opportunity to represent science information in creative ways. Importantly, when asked at interview, '*How do you think making a slowmation impacted upon your learning?*', students believed their enjoyment facilitated better learning outcomes than teaching as usual. Students contrasted their experience constructing a slowmation with their usual experience learning science by "reading from textbooks" and "writing on a worksheet", and perceived their learning to be greater in the context of constructing a slowmation: "It's better than doing normal stuff in class and it helps you understand it more." (Ellie). Excerpts 6.9 to 6.11 illustrate students expressing this viewpoint at interview:

Excerpt 6.9

Researcher: How did you find making a slowmation?

Will: It was fun.

Researcher: Was there something that stood out as being really fun?

Will:	I liked making the slides *[still images]* and seeing it all come together.
Researcher:	How do you think making a slowmation impacted your learning?
Will:	It helped me more because I prefer hands-on *[learning]* instead of just writing and talking. That helped me understand more.

Excerpt 6.10

Researcher:	Can you tell me about your experience making a slowmation?
Lilly:	It was fun.
Researcher:	Was there something in particular that was really fun?
Lilly:	I liked the whole thing. Instead of reading from textbooks and stuff it was more fun. It was interesting for me to make stuff and it taught me more.
Researcher:	Why was it interesting to learn that way?
Lilly:	Because we actually got to do stuff other than reading and writing.

Excerpt 6.11

Researcher:	Can you tell me about your experience making a slowmation?
Louisa:	It was actually pretty fun. If Teacher A were teaching us that I don't think I would remember as much as I did.
Researcher:	Why is that?
Louisa:	Because I don't usually listen in class.
Researcher:	Why was doing the slowmation different?
Louisa:	Because you had to learn the stuff and apply it. You weren't just writing it down you had to make stuff. It's a more enjoyable way to do it. Instead of writing on a worksheet for 70 minutes it's taking pictures of the bits and pieces you've created.

6.4 Key Finding 2: Pedagogical Issues Associated with Constructing a Slowmation Inhibited Opportunities for Conceptual Change

Although in some ways constructing a slowmation facilitated students' learning, significant pedagogical issues arose from implementing this instructional approach in a junior secondary school context that appeared to inhibit opportunities for conceptual change. The analysis of classroom audio recordings suggests that such opportunities were constrained by: (1) students' preoccupation with the procedural aspects of constructing a slowmation; (2) students' apparent lack of motivation to understand the science content and represent it accurately; (3) students' privileging and bypassing particular modes of representation; and (4) time constraints. In the sections that follow, the data that supports each of these themes are presented in turn.

6.4.1 Students were preoccupied with the procedural aspects of constructing a slowmation

The most prominent theme that arose from data analysis, evident across all groups, was students' preoccupation with the procedural aspects of constructing a slowmation. The majority of discussion that occurred while students constructed their slowmation was focused on the mode of representation, design elements, sequence and timing of the slowmation (Table 6.2). Although it was necessary for students to discuss these factors, the hundreds of distinct references to procedural aspects across the transcripts demonstrate that this was an extremely pervasive theme.

Table 6.2
A summary of the data pertaining to students' preoccupation with the procedural aspects of creating a slowmation

Feature		Example quotation	Number of instances
Mode of representation			
Diagram	Michael:	Get an image up of a tectonic plate and we'll just do a diagram.	44
Text	Ellie:	We need to label it to say 'Pangaea'.	40
Model	Anna:	We're going to get two pieces of clay and slowly move them together.	26
Narration	Sam:	We could have somebody narrating that?	17
	Melanie:	That's a good idea!	
Photograph	Teacher:	What do you need to use the Internet for?	3
	Sam:	We're going to search up a picture of the plates to use.	
Design element			
Materials	Researcher:	What are you going to use for the plates? Paper?	30
	Amanda:	Yep.	
Colour	Jackson:	We'll want at least a couple of different colours of clay.	23
Size	Will:	They're all the same size. I made sure they're all three centimetres.	10
Sequence	Paul:	Should we include some of the mountain ranges that have been formed by these?	25
	Jackson:	Yeah.	
	Teacher:	Are you going to put that early or later in the piece?	
	Paul:	Later on.	
Timing	Sarah:	We'll have to make it slower, obviously.	37

Most of the discussion generated between students centered on the modes of representation they would use in their slowmation (i.e., text, diagrams, photos, models and/or narration). The design of the specific representations (i.e., material, colour and size) was also frequently discussed. Although still mentioned a substantial number of times, students were less concerned with the sequence and timing of information in their slowmation. No evidence could be found in the data of students' discussions about the attributes of their animations (e.g., the size and colours of their models) being indicative of science learning (e.g., deliberately using different colours to represent different layers of the earth). As evident in the example quotations provided in Table 6.2, no conceptual development occurred during these discussions, presumably because students were not focused on the science that they were trying to represent.

Interestingly, during the post-instruction interviews, Trevor's learning was primarily about the procedural skills associated with constructing a slowmation. When asked about his experience making a slowmation, he indicated that he learnt a lot about "animation techniques" and "the most memorable part was learning … how to use the *[MyCreate™]* program."

6.4.2 Students lacked motivation to understand the science content and represent it accurately

There were 32 instances where students appeared to lack motivation to understand the science content and represent it accurately in their slowmation, as encapsulated by the following quotation: "She *[the teacher]* won't see it *[the research notes]*. It doesn't really matter if you don't understand what it's saying." (Louisa). The following excerpts document occasions where there were opportunities for conceptual development, but these opportunities were not realised. In each case, it seems that students were not motivated to understand better the science that they were trying to represent through their models:

Excerpt 6.24

Louisa:	What do they *[tectonic plates]* look like? Are they just, like, ovals?
Ellie:	Yeah I assume so.

Excerpt 6.25

Researcher:	Do you think paper is the best way to represent a tectonic plate?
Melanie:	We could use a sponge or something because it's thicker.
Researcher:	It is thicker. Well what is a tectonic plate made up of?
Melanie:	The crust?
Researcher:	And?
Melanie:	Other stuff.

Excerpt 6.26

Amanda:	OK we didn't explain anything. Because it goes, "Mountains are caused by continental convergent plates", but we never really say how they form. Is it just, like, when they hit each other or something?
Melanie:	Yeah it's when they hit each other. Maybe we'll have to narrate that.

The following remarks from students provide further evidence of students' waning motivation to develop a deep understanding of the science content:

- "You don't have to do it perfectly! We're not being marked on this." (Michael)
- "It's good enough. It doesn't need to be perfect." (Anna)
- "That doesn't make any sense to me, but that's what my book says." (Amanda)
- "It's not right, but that's what we're doing." (Louisa)

Students often experienced difficulty locating and comprehending information on the Internet during the researching stage, which could have impeded their willingness to come to understand the material. With regards to locating information on the web, remarks such as, “What did you search up to get your answer?” and “Where did you find that?” occurred throughout the researching phase. Comprehending what they had found presented further challenges for students. Louisa noted that, “There are a lot of complicated words that I don’t know”. This sentiment was echoed by other students: “It doesn’t really make sense. It says, ‘oceanic plates’, what the hell is that?” (Ellie). As illustrated by Louisa and Ellie’s remarks, learning about difficult and abstract geologic concepts through self-directed research was a challenging task. This difficulty is exemplified further by Anna’s remark that, “I just didn’t understand because no one was explaining it to me.” This sentiment was echoed during the post-intervention interviews, as students recalled the challenge of finding and comprehending information during self-directed research on the Internet:

Excerpt 6.27

Researcher:	Were there any challenges *[constructing a slowmation]*?
Lilly:	When we were making the storyboard it was hard to come up with ideas. And some of the information we got was wrong so we had to go back and fix it.

Excerpt 6.28

Researcher:	Were there any challenges *[constructing a slowmation]*?
Melanie:	If we didn’t have the right information then it was difficult.
Researcher:	From the research phase?
Melanie:	Yeah.

Excerpt 6.29

Researcher:	What was most memorable [*about the process of constructing a slowmation*]?
Anna:	Seeing it at the end. Watching it in class.
Researcher:	How did it make you feel?

Anna:	I was a bit embarrassed because we didn’t know what we were talking about.
Researcher:	Why is that?
Anna:	Because we didn’t research as much as we could have. It was too hard.

Often students did not represent the science content accurately in their slowmation. In these instances, students were more concerned about designing an entertaining slowmation than ensuring it was scientifically accurate. Note the following discussion in Excerpt 6.30 where Lilly identified that her group “just wanted it *[the slowmation]* to be fun.”

Excerpt 6.30

Researcher:	Is that just to reveal your title?
Sarah:	Yeah.
Researcher:	Are they representing a tectonic plate?
Sarah:	Yeah technically diverging plates.
Kate:	It was my idea!
Researcher:	It’s not very scientific at the moment.
Sarah:	Why?
Caitlyn:	[Why?]
Researcher:	Did you find out what makes up a tectonic plate? Where are the crust and the upper mantle on your model? Do you know what I mean? At the moment it just looks like two sponges.
Sarah:	((Laugh))
Lilly:	We just wanted it to be fun!

Interestingly, on one occasion, a student understood the science content but was seemingly unable to represent her understanding accurately. Sarah noted that, “It’s hard to show that it’s *[the tectonic plate]* moving!” while she was modeling.

6.4.3 Students privileged and bypassed modes of representation

One of the merits of slowmation that is documented in the pre-service teacher education literature is that it affords students opportunities to represent information in multiple modalities (i.e., research notes, storyboard, physical models, text and narration), or a semiotic progression (Hoban et al., 2011). In the current study, however, the data suggests that students privileged particular modes of representation (namely, narration and text [definitions and dot point summaries]) and chose not to employ other more cognitively demanding ones, such as physical models. In doing so, there were fewer opportunities for students to develop their conceptual understanding as they transformed information from one mode to another.

In the following excerpts, students relied on text and narration to communicate science ideas. For example, in Excerpts 6.31 and 6.32, the students discussed writing definitions of tectonic plates to appear in their animations, presumably because it was the simplest way to communicate their knowledge:

Excerpt 6.31

Michael:	So let's start making the sequencing stuff.
Will:	Yes. So in the first sequence we could write the definition of a tectonic plate. So um…
Michael:	What is a tectonic plate? Go back.
Will:	No we'll just put, ((Writing)) "Write definition of a tectonic plate."
Michael:	Go on then.

Excerpt 6.32

Sarah:	OK we need to write the definition of a divergent plate boundary. Ours is going to be so boring.
Lilly:	Well go and see what other people are doing and see if theirs is just as boring.
Sarah:	Everyone else is using clay.

Lilly: So what?

Excerpt 6.33

Sam: I think we should explain what tectonic plates are. Um::: We could have somebody narrating that?

Melanie: That's a good idea!

The following excerpts illustrate students bypassing the use of three-dimensional physical models in favour of drawings or sketches. Again, it is likely that this presented an easier option than constructing models out of clay or other materials:

Excerpt 6.34

Researcher: So you're doing all of yours as a sketch? You're not going to use any models?

Michael: No.

Will: [Probably not.]

Researcher: OK. You'll have to make sure your diagrams are really detailed and accurate.

Excerpt 6.35

Researcher: Are you going to make some models to move around?

Lilly: Maybe we could but we (are drawing them).

Researcher: Oh you're *only* drawing?

Lilly: Yes.

6.4.4 Constructing a slowmation took students "longer than expected"

Another prominent theme that arose from the analysis of the audio-recordings was that the limited period of time over which the project was implemented (recall that the project took place over a series of four, 70-minute lessons; see Chapter 3). Thirty-five instances were drawn from the transcripts wherein students indicated that they did not have enough time to properly complete their slowmation. The time constraints placed upon students were evident in exclamations like, “We’re only up to the first question!” (Melanie), and “We only have half an hour left! I didn’t think we’d finish!” (Will). Melanie noted that, for her, constructing a slowmation took “… a lot longer than … expected.” The teachers, too, were aware of the limited time available. Throughout the construction process they prompted students to “Hurry up!” and “Get a move on!” (Teacher A). The lack of time also arose as an issue during the post-intervention interviews when students were asked about the challenges they encountered while constructing a slowmation.

Students generally found the stop-motion aspect of slowmation to be the most time consuming task. This was apparent when students opted out of manipulating their models because it was too time consuming. For example, in Excerpt 6.11, the researcher noticed that one group of students was not incorporating the stop-motion characteristic of slowmation in their animation by frequently manipulating and photographing models. Instead, they were creating a slideshow-style presentation. Similarly, Excerpts 6.12 and 6.14 illustrate how students chose to minimise the amount of stop-motion required to construct their animations.

Excerpt 6.12

Researcher:	Remember, because it’s a stop-motion animation, you might like to do it letter by letter.
Anna:	Yeah, but that takes too much time.

Excerpt 6.13

Anna:	They’re moving together and then they kind of like-
Jackson:	Collide with each other?
Paul:	Do you know how long… If we do that step-by-step it will take us too long to create! We’re not doing that!

Excerpt 6.14

Will: Should we do it *[their diagram of tectonic plates]* moving?

Michael: Nah, that would take way too long. Because this is already the third lesson.

There were instances when the time constraints of the study led students to rush the construction of their animations. In Excerpt 6.15, for example, Ellie and Louisa were trying to accurately represent plate movement at their chosen tectonic plate boundary, however they did not have time to discuss their learning with one another:

Excerpt 6.15

Ellie: We have to hurry up! Just do whatever!

Louisa: I don't know what way it's supposed to be though!

Ellie: It doesn't matter! Just do whatever!

Students also commented that they felt rushed at interview. Amanda recalled that "… everyone did rush a little bit and some groups ran out of time." Likewise, it was noted by Will that "… the most challenging thing was finishing in the time frame." In order to finish the slowmation in the four 70-minute lessons, his group "didn't do everything *[they]* wanted to" and " had to cut a few parts out."

Throughout the construction process, students spent a considerable amount of time revisiting and clarifying the task requirements. There were 25 instances where students asked their teacher or peers to explain an aspect of the task, which contributed further to the time pressures that they experienced. This occurred throughout the researching, storyboarding and construction phases, as demonstrated in Excerpts 6.16 to 6.18. Perhaps this is not surprising given that this task was relatively new and unfamiliar to students.

Excerpt 6.16

Ellie:	OK do we all have to write it [*i.e. information from the Internet*] down?
Louisa:	Yeah.
Jason:	[Yeah.]
Louisa:	Do we have to change it into our own words?
Ellie:	Yeah.

Excerpt 6.17

Trevor:	So in this task … What is the task exactly?
Zach:	Is each sequence a photo?
Joe:	Yeah, each sequence is a photo. I think.

Excerpt 6.18

Paul:	Sir, can you check this?
Researcher:	Where are your models? Have a look around the room for some ideas. I know you're stuck because a group member is away but this isn't very scientific.
Jackson:	Yeah.
Researcher:	Remember your slowmation should be answering five questions. Check Paul's task sheet.

Students also spent a considerable amount of time deciding how the workload would be shared amongst group members. There were 52 instances where students assigned roles (e.g., researcher, photographer and narrator) amongst themselves. Notably, students seemed to dislike narrating their slowmation:

Excerpt 6.19

Trevor:	Who's going to do narration? Do you wanna do it? Rock, paper, scissors?
Zach:	Nah yesterday we already had it worked out.

Trevor: Joe is not here so we have to alter our roles. I got all the stuff and set it up so I'll take the pictures if you narrate.

Excerpt 6.20

Sarah: We've got to get the narration done.
Kate: That can be next lesson.
Sarah: Can someone else *please* do the narration?
Lilly: No way! My voice sounds stupid.
Sarah: But I *hate* my voice!

On two occasions, the assignment of roles caused discord between the students, compounding the time constraints of the project. In Excerpt 6.21, Lilly was concerned that her group members were "looking up videos" on the Internet rather than carrying out the research for their slowmation:

Excerpt 6.21

Lilly: Guys can you just research?
Sarah: We are! I'm trying to find videos on it.
Lilly: Like you were!
Kate: [We are!]
Sarah: I wasn't looking up videos, I was just…
Lilly: You are!
Sarah: I'll search up 'slowmation' then.

Lilly noted during her post-intervention interview, "You've got to get your team to work together. I think that was probably the most difficult thing." Anna, who also experienced difficultly getting her group to "work together", shared similar concerns during her interview:

Excerpt 6.22

Researcher:	Can you tell me about your experience making a slowmation?
Anna:	It was OK. It was a little hard.
Researcher:	Why is that?
Anna:	Well we weren't actually cooperating.
Researcher:	Oh! Did you have problems working in a group?
Anna:	Well Jackson and I were fine but Paul didn't want to do anything.

Finally, during the construction phase, one group's slowmation was deleted from their iPad™, which had a significant impact on that group's ability to finish their slowmation in the allocated amount of time:

Excerpt 6.23

Sarah:	Sir! The app froze and then it closed and we went back into it and it deleted our whole thing!
Researcher:	Really?
Kate:	Yes! And we had 110 frames on there!
Researcher:	Isn't that weird?
Sarah:	It deleted everything.
Researcher:	OK you'll have to re-do it really quickly.
Lilly:	How are we supposed to re-do it quickly!
Researcher:	You'll just have to keep your chin up and do your best.
Lilly:	OK.
Sarah:	((Sigh)) I'm really sad. We had so much.
Kate:	I know.

6.5 Chapter Summary

Overall, constructing a slowmation provided opportunities for conceptual development through discrete episodes of teacher instruction, and by stimulating students' enjoyment and willingness to learn. The importance of teacher intervention in identifying and addressing students' alternative conceptions was highlighted by one instance wherein two students' alternative conception about the formation of mountains and volcanoes persisted through the construction process. Despite these affordances, however, significant pedagogical issues arose from the use of slowmation construction as an instructional strategy in a junior secondary school context. First, students were preoccupied with the procedural aspects of constructing a slowmation. This included the content, mode of representation, design elements, sequence, and timing of the slowmation. Second, students demonstrated waning motivation to understand the science content and represent it accurately. Instead, they were concerned with the aesthetics of their slowmation (i.e., whether it looked "cute" or was "fun" to watch). This, in part, appeared to be due to the student-directed research at the beginning of the construction process, which students found particularly challenging. Third, students privileged 'easy' modes of representation such as text, and bypassed more challenging modes of representation such as physical models. This may have reduced the opportunities for conceptual development, as students avoided transforming the science content from one representation to another. Fourth, the time constraints of the research project compromised the quality of students' slowmations. The stop-motion aspect of slowmation took "way too long" to complete, and students spent a considerable amount of time assigning and re-assigning roles (e.g., researcher, scribe, photographer and narrator) amongst themselves. Students also had to regularly seek clarification about the requirements of the task. These findings have important implications for our understanding of the value of using slowmation as a conceptual change strategy in a junior secondary science context. As such, they informed the development of a pedagogical framework for constructing slowmations with school-aged learners. This framework is presented and discussed in Chapter 7, as are the significance and implications of the broader findings presented in the current chapter.

CHAPTER SEVEN: DISCUSSION

7.1 Introduction

In response to the need for research into conceptual change instructional approaches in the Earth science discipline (Chapter 2), the current study investigated the use of slowmation in a junior secondary Earth science context. This chapter will now review the aims of the study, and discuss its findings and their implications. Section 7.2 presents a review of the aims of the study, the research methodology and procedures adopted, and the research questions investigated. Sections 7.3 to 7.5 present and discuss three assertions that have arisen from the data, and in doing so, provide answers to the study's three research questions. These assertions refer to: (1) the enhancement of students' conceptual change through their participation in the construction of a slowmation; (2) the positive relationship between students' conceptual change and their interest and enjoyment; and (3) the need for a pedagogical framework to inform the use of slowmation with school-aged learners. In response to the final assertion, Section 7.6 describes a pedagogical framework informed by the findings of this study: the *Learning with Slowmation* (LWS) framework. The limitations of this study are discussed in Section 7.7, while the implications for science learning and science education research are presented in Section 7.8. The final section of this chapter, Section 7.9, summarises the contribution this study makes to science education practice and theory.

7.2 Review of Aims, Research Methodology and Research Questions

The principal aim of this research project was to investigate how constructing a slowmation influenced Year 9 students' conceptual change, and the relationship between students' interest generated by the project and their conceptual change. The study was conducted with junior secondary science students at Pine Mountain State College, a Preparatory to Year 12 college in South-East Queensland. Four intact groups of participants (i.e., four Year 9 science classes, N=95) were randomly assigned to intervention and comparison conditions. While two intervention classes (N=52) created a slowmation to represent a type of tectonic plate boundary, two comparison classes (N=43) experienced 'teaching as usual', in alignment with the College's usual program of instruction. Both the intervention and comparison conditions spanned four 70-minute science lessons. A two-tiered multiple-choice test was administered to determine the effect of creating a slowmation on students' conceptual change, and data on students' individual and situational interest were generated using items adapted from the *Situational Interest Survey* (Linnenbrink-Garcia et al., 2010) and the *PISA 2006 Student Questionnaire* (OECD, 2006). More nuanced qualitative data were generated by audio-recording a sub-sample of students while they constructed their slowmation (*N*=19), and at post-intervention interviews with the same students. The study was guided by the investigation of the following research questions:

1. Does the process of constructing a slowmation have a significant effect on students' conceptual change?
2. How does the process of constructing a slowmation influence students' conceptual change?
3. To what extent is students' interest, generated by their participation in constructing a slowmation, a predictor of their conceptual change?

In answering these questions, three assertions have been synthesised from the quantitative and qualitative results presented in the preceding chapters:

Assertion 1: The construction of a slowmation significantly enhanced students' conceptual change as it afforded 'teachable moments';

Assertion 2: Students' interest and enjoyment, generated by their participation in constructing a slowmation, facilitated conceptual change; and

Assertion 3: Pedagogical considerations warrant the development of a framework to inform the use of slowmation with school-aged learners.

Assertion 1 answers Research Questions 1 and 2, while Assertion 2 answers Research Question 3. Although Assertion 3 does not directly answer a research question, it reflects the significance of the unexpected findings that arose from the analysis of the think-aloud data. It also raises questions about the adequacy of existing learning frameworks that inform the use of slowmation, particularly with school aged learners, and has substantial implications for the development of a new learning framework, presented later in this chapter. As such, the discussion of Assertion 3 is warranted and justified. Each of these assertions will now be discussed in detail.

7.3 Assertion 1: The Construction of a Slowmation Significantly Enhanced Students' Conceptual Change as it Afforded 'Teachable Moments'.

Evidence of students' conceptual understanding about plate tectonics was generated from two data sources: students' responses to the GeoQuiz, pre- and post-intervention; and audio-recordings of students thinking aloud while they constructed their slowmation. In response to Research Question 1, the analysis of the GeoQuiz data provides evidence to suggest that constructing a slowmation significantly enhanced students' conceptual change. In response to Research Question 2, the analysis of audio-recordings revealed that the construction process afforded teachable moments wherein students' alternative conceptions were identified and corrected by the teacher.

The GeoQuiz examined students' conceptual understanding of plate tectonics; specifically, their conceptual understanding of the nature and movement of tectonic plates, and the geologic processes that operate at tectonic plate boundaries. The intervention and comparison groups both demonstrated an increase in the number of students with scientific conceptions and a decrease in the number of students with alternative conceptions, from pretest to posttest. The results of a repeated measures ANOVA and subsequent paired samples *t*-tests revealed that the change in both groups' GeoQuiz scores was statistically significant (Chapter 5, Table 5.5). Importantly, this indicates that students' participation in the construction of a slowmation led to statistically significant conceptual change [$t(95) = -4.72$, $p < .001$, $d = .91$].

The analysis of students verbalising their thinking during the slowmation construction process identified instances wherein their conceptual development was enhanced. It was found that the classroom teacher was solely responsible for identifying and correcting students' alternative conceptions (Chapter 6, Excerpts 6.1-6.9). These teachable moments, which occurred exclusively throughout the construction phase only, provided opportunities for the teacher to view students' representations and prompt them to consider their accuracy. It is to be noted that teachable moments are described as bringing about conceptual development (i.e., the addition of scientific ‘elements’ to an existing conception), rather than conceptual change (i.e., the complete replacement or modification of an existing conception). When considered alongside the results of the GeoQuiz, however, it is likely that these teachable moments played a critical role in contributing to students’ overall conceptual change through the repeated addition of scientific elements to their existing conceptions. This is consistent with contemporary notions of conceptual change that suggest it is a gradual process of knowledge restructuring (Vosniadou & Ioannides, 1998). Without this input from the teacher, it appeared that students’ alternative conceptions remained unchallenged and persisted (Chapter 6, Excerpt 6.36).

These findings extend and support existing research on the value of constructing slowmation representations in science education. As demonstrated in Chapter 2 (Section 2.5.2), there is a paucity of research on the value of slowmation construction with school-aged learners. The researcher is only aware of two published conference proceedings (Hoban et al., 2007; Kidman & Hoban, 2009) and two published journal articles (Brown et al., 2013; Jablonski et al., 2015) that have explored this problem. Only one of these studies has investigated the value of the construction process for junior secondary school students (Jablonski et al., 2015). The findings of the current study complement those reported by Jablonski et al. (2015), as both studies found that constructing a slowmation had a statistically significant positive impact on students’ learning.

Unlike the study conducted by Jablonski at al. (2015), however, the current study adopted a conceptual change perspective of learning, and therefore investigated the extent to which the slowmation construction process resolved students’ alternative conceptions. In doing so, this study’s findings support emerging research from pre-service teacher education contexts. Most recently, Nielsen and Hoban (2015) found that constructing a slowmation increased pre-service teachers’ scientific understanding of moon phases and reduced their alternative conceptions. Similar findings have been demonstrated in other research specific to slowmation construction in pre-service teacher education (Hoban & Nielsen, 2012, 2014; Kidman et al., 2012; Nielsen & Hoban, 2015; Loughran et al., 2012).

In this body of research, the process of creating a slowmation afforded pre-service teachers multiple opportunities to revise their understandings, as they translated science information between several modes of representations (i.e., research notes, storyboards, models, digital photographs and the final slowmation). Pre-service teachers also drew upon their prior knowledge of the topic to engage in scientific reasoning and argumentation with their peers, resulting in cogenerative dialogue that facilitated conceptual change. The findings from the current study are very different, as the teacher was solely responsible for identifying and correcting students' alternative conceptions; there appeared to be no other influences impacting upon students' learning. This suggests that the slowmation construction process has different affordances for pre-service teachers and school-aged students.

In previous studies, pre-service teachers translated information between several modes of representation in a cumulative semiotic progression during the construction process (Hoban et al., 2011). This offers significant affordances for conceptual change, as the resilient nature of alternative conceptions means that knowledge restructuring is unlikely to occur until pre-service teachers experience several encounters with science content (Hoban & Nielsen, 2013). A crucial aspect to this progression of meaning is its iterative nature, which involves the "*recursive checking of information* with the Internet and with previous representations" (Hoban et al., 2011, p. 1002, emphasis added). In the current study, some students successfully translated information in a cumulative semiotic progression. While these students checked the accuracy of their representations with the teacher, which provided teachable moments, other students did not demonstrate the same motivation to represent information accurately. Rather than recursively checking information and iteratively evaluating their representations, such students were more concerned with ensuring that their slowmation was aesthetically pleasing and entertaining (Chapter 6, Excerpt 6.30). Moreover, some students experienced difficulty finding and comprehending information on the Internet, which may have impeded their willingness to iteratively check the accuracy of information between translations from one mode of representation to another. These pedagogical issues have not arisen in pre-service teacher education, and will be discussed further later in this chapter.

Notably, the teachable moments that occurred in the current study resonate with how Kidman and colleagues (2012) conceptualise learning with slowmation. Their *Model of Learning and Re-learning Through Slowmation* (Kidman et al., 2012) depicts two pathways available for learners who are constructing a slowmation: a surface learning pathway, and a deep learning pathway (Chapter 2, Section 2.5.3). The model explicitly identifies the teacher as crucial to bringing about ‘deep learning’. Kidman et al. (2012) suggest that throughout the construction process, the teacher has a responsibility to ensure that students consider the accuracy of their representations and respond by revising the flawed characteristics. This was observed in the current study, and proved to be crucial in facilitating students’ conceptual change.

Cogenerative discussion has also facilitated pre-service teachers’ conceptual change when learning with slowmation. Hoban and Nielsen (2014) assert that by “questioning, stating [their] beliefs, seeking evidence and … making [knowledge] claims” (p. 74), pre-service teachers are able to resolve their alternative conceptions. This was not observed in the current study. It is possible that pre-service teachers have greater prior knowledge than school-aged students, which enables them to more effectively participate in cogenerative discussion about the science concept or process being represented. In addition, if the pre-service teachers do not have substantial prior knowledge, they are likely to be more capable than school-aged students of finding and comprehending the information necessary to make and justify knowledge claims. As previously mentioned, students in the current study found this self-directed research a complex task, and so rather than evaluating their developing knowledge as they encountered new or discrepant information, students tended to simply agree with one another, even if the science content was incorrect (Chapter 6, Excerpts 6.24-6.26).

An affordance for facilitating cogenerative discussion that was not apparent in the current study was pre-service teachers' "need to understand the science in order to explain it" (Hoban & Nielsen, 2014, p. 74). Hoban and Nielsen (2014) attributed pre-service teachers' 'need to know' to the task's authentic purpose – to create an explanatory resource for Year 6 primary school children. Although students in the current study were also given a purpose for constructing a slowmation (i.e., to present their animation to younger students), this did not appear to provide sufficient motivation to help them to understand the science content and represent it accurately in their slowmation. Perhaps, then, further strategies to maximise opportunities for cogenerative discussion are required when enacting slowmation with school students. For school-aged learners, this may require explicit instruction in cogenerative dialogue before commencing the planning phase, so that it becomes part of the pedagogy that supports the use of slowmation in the classroom, and students have the tools required to discuss their learning as it takes place.

Having contrasted how pre-service teachers and school-aged students learn with slowmation, there are other findings arising from the current study that warrant attention. First, a noteworthy finding drawn from students' GeoQuiz responses was the prevalence of alternative conceptions at pretest. The data show that students in both conditions had many alternative conceptions about plate tectonics, most of which have not been reported in previous research (Mills et al., 2017). Students' alternative conceptions most commonly concerned the formation of landforms at tectonic plate boundaries, and students were particularly confused about the cause of subduction at an oceanic-continental convergent plate boundary. It is also possible that the Australian context of the research contributed to the novelty of this finding, as previous research reporting school and university students' conceptions of plate tectonics originates from elsewhere (e.g., Marques & Thompson, 1997).

Second, upon closer examination of students' conceptions about the nature and movement of tectonic plates from pretest to posttest, it seems that students in the comparison group had greater learning gains than students in the treatment group (Chapter 4, Section 5.2.1.1). This is likely due to a difference in the enacted curriculum in the first lesson of the study. When conceptualising the intervention and considering what questions would guide students' independent research, the researcher assumed that students would spend an equal amount of time researching each key question (Chapter 3, Section 3.4.1). This was not the case, however. Students spent very little time researching the first two questions, *'What are tectonic plates?'* and *'What causes tectonic plates to move?'*, and considerably more time researching the remaining questions concerning the formation of landforms at tectonic plate boundaries. This was presumably because students focused their research on the questions that directly related to the topic of their slowmation. While the intervention group started their self-directed research about tectonic plate boundaries, the comparison group participated in a lesson entitled '*Heat and Convection*' (Chapter 3, Section 3.4.1). It is likely that this contributed to the comparison group having a better understanding of the nature and movement of tectonic plates as they experienced explicit instruction about this topic, while the intervention group did not.

Third, although the findings from the GeoQuiz show that constructing a slowmation had a significant effect on students' conceptual development, it was no more effective than teaching as usual. One possible explanation for this finding is the pedagogical issues that appeared to constrain students' conceptual change (e.g., students' preoccupation with the procedural and design elements of their slowmation, and time constraints). If these issues were not present, opportunities for conceptual change may have been enhanced further. Although it is not appropriate to make assumptions beyond this based on the data generated in the current study, previous research can be used to consider this finding. It is possible that more than one group of students in the intervention condition incorrectly represented concepts throughout their slowmation. These flawed representations may have remained undiagnosed by the classroom teacher, thus reinforcing other students' alternative conceptions during the presentation stage. This has occurred in previous studies where students were creating their own representations of scientific phenomena (e.g., Ogan-Bekiroglu, 2007; Trundle et al., 2002). Alternatively, students may have experienced difficulty using the technology or application *MyCreate*™. This arose as a concern in one study where pre-service teachers created a slowmation (Hoban & Nielsen, 2012). Finally, it is to be noted that both groups participated in a sequence of lessons involving the construction of multiple representations; the only difference between the two conditions was that the intervention group was assisted by the use of technology. Perhaps, then, this finding simply reflects the value of student-generated multi-modal representations in learning science (Ainsworth, 1999, 2008; Kozma, 2003).

7.4 Assertion 2: Students' Interest, Generated by their Participation in Constructing a Slowmation, Facilitated Conceptual Change.

Evidence of students' individual and situational interest, and enjoyment, was generated from responses to the SILS survey and post-intervention interviews, respectively. The SILS survey consists of 24 items within five subscales that measure aspects of students' individual and situational interest: namely, their interest in learning about science; enjoyment learning about Earth science; triggered-SI; maintained-SI-feeling; and maintained-SI-value. In response to Research Question 3, data generated from the SILS survey support the assertion that students' interest, generated through the construction of a slowmation, facilitated their conceptual change. While students' enjoyment elicited by the construction of the slowmations was a salient theme to emerge from the qualitative data analyses, a statistically significant relationship between students' conceptual change and their enjoyment learning Earth science (as measured by the SILS survey) was not found. It is possible, however, that students' enjoyment associated with the construction of a slowmation, as articulated at interview, also facilitated their learning. Importantly, it is to be noted that students' enjoyment referred to here was *generated by their participation in the construction of a slowmation*, and not aroused by the topic (plate tectonics), or by Earth science, more broadly, as measured by Subscale 2 on the SILS survey.

The quantitative analyses of the SILS survey data demonstrated a statistically significant increase in the interest in learning about science [$t(95) = -3.48$, $p = .001$, $d = .49$], interest in learning about geology [$t(95) = -3.86$, $p = .000$, $d = .53$], triggered-SI [$t(95) = -3.24$, $p = .002$, $d = .46$] and maintained-SI-feeling [$t(95) = -2.83$, $p = .007$, $d = .40$] subscales, for students who participated in the construction of a slowmation. There was a statistically significant decrease in the triggered-SI subscale for students who experienced 'teaching as usual' [$t(95) = 2.38$, $p = .018$, $d = .37$]. These results suggest that students' individual interest in learning about science and geology, and components of their situational interest, were enhanced by their participation in the construction of a slowmation. Modest effect sizes were observed in all cases; the largest of which was observed for students' interest in learning about geology ($d = .49$), which represents the greatest increase from pretest to posttest.

Data generated from interviews with students upon completion of their slowmation provide further evidence to support this assertion. Students indicated that they enjoyed the hands-on construction process and the opportunity to represent science information in creative ways. Importantly, when asked at interview, '*How do you think making a slowmation impacted upon your learning?*', students believed their enjoyment facilitated better learning outcomes. Students contrasted their experience constructing a slowmation with their usual experience learning science and perceived their learning to be greater in the context of constructing a slowmation. This was apparent in remarks such as: "It's better than doing normal stuff in class and it helps you understand it more." (Ellie).

Recent research that has occurred at the crossroads of science education and educational psychology offers an explanation for this finding. Although individual interest and situational interest were conceptualised distinctly in this study (Chapter 4, Section 4.4.1), some researchers propose that situational interest can develop into individual interest over time (e.g., Hidi & Renninger, 2006; Krapp, 2002). This occurs because students who find learning a particular topic engaging (triggered-SI) and meaningful (maintained-SI) are more likely to value the material beyond a given learning context and may seek out new opportunities to expand their knowledge (Linnenbrink-Garcia et al., 2010).

Such transformation was observed in the current study, as learning with slowmation stimulated students' interest in learning about science and geology. This is presumably due to the engaging characteristics of this type of instruction, such as its hands-on nature and use of hand-held digital technology. This is evidenced by a significant increase in students' triggered-SI and maintained-SI-feeling, over the course of the project. This is further supported by students' comments at interview, which suggest that they enjoyed learning differently in science, and they perceived slowmation to enhance their learning.

Interestingly, although students' interest in learning about science and geology were enhanced by their participation in the construction of a slowmation, their enjoyment learning Earth science only marginally increased. While this is an unusual finding, as the relationship between interest and enjoyment is generally reciprocal (Ainley & Hidi, 2014; Izard, 2007, 2009), it is perhaps not surprising in light of students' negative perceptions of Earth science identified at the onset of this thesis in Chapter 1 (Section 1.1). Students' perceptions of Earth science topics as difficult (Dawson & Carson, 2013) offers one explanation for this finding, as although students experienced feelings of wanting to know more about science and geology, there remained an absense of pleasure, and satisfaction of achievement, in students' engagement with the subject matter (Ainley & Hidi, 2014). This is supported by literature noting that situational interest does not necessarily generate positive feelings, and can even be triggered in situations that arouse negative affect (e.g., frustration) (Hidi & Harackiewicz, 2000). In the context of the current study, this means that although the construction process aroused students' interest in learning about science and geology, this did not translate to positive feelings towards the discipline-specific content knowledge itself.

Overall, the relationship between interest and conceptual change presents a substantial research finding. While previous research has suggested that slowmation can enhance students' attitudes towards learning general science (Hoban & Nielsen, 2012), the present research is the first of its kind to provide an in-depth examination of how creating a slowmation impacts students' interest in a specific science discipline. More research of this nature is needed in Earth science education amidst research that shows this subject has the lowest non-compulsory participation out of all science disciplines in schools (Ainley et al., 2008); students' perceive the subject to be difficult and boring (Dawson & Carson, 2013); and teachers are underprepared to teach about geological phenomena and address students' firmly held alternative conceptions about Earth's physical processes

(Dawson & Moore, 2011; Stoltman et al., 2015). This research agenda is urgent given that students who experienced teaching as usual in the current study reported a significant decrease in their situational interest from pretest to posttest. It seems that although students had low levels of interest in geology to begin with, their learning experiences eroded their interest further. This highlights further the importance of engaging instructional approaches like slowmation.

Perhaps more important than students' increase in interest over the course of the research project, is the significant relationship between aspects of students' interest and their conceptual change. Further quantitative analyses of the SILS survey data revealed that there was a significant positive relationship between students' individual interest in learning science and their conceptual change, $r(50) = .29$, $p = .037$, their triggered-SI and conceptual change, $r(50) = .40$, $p = .004$, and their maintained-SI-feeling and conceptual change, $r(50) = .38$, $p = .006$. Finally, students' overall interest, generated by their construction of a slowmation, was found to be a significant predictor of their conceptual change.

This finding contributes to the existing research on students' interest and conceptual change, noting that opposing results have been reported in the literature thus far. As identified in Chapter 2 (Section 2.3.2), interest is a variable that has the potential to facilitate students' conceptual change (Pintrich et al., 1993). As interest was positively related to conceptual change in the current study, it supports research conducted by Andre and Windschitl (2003) and Mason and her colleagues (2008) that report the same finding. On the other hand, it is at odds with other research that suggests highly interested students are less likely to change their existing conceptions when presented with new or discrepant information (Alexander, 2004).

More broadly, this research finding challenges traditional notions of conceptual change by adopting a cognitive-affective perspective. As articulated in Chapter 2 (Section 2.3.2), despite the overwhelming and longstanding argument for further research into the interplay between students' affect and conceptual change (Cobern, 1994; Pintrich et al., 1993; Sinatra & Mason, 2013; Treagust & Duit, 2008; Tytler & Prain, 2010; West & Pines, 1983; Zembylas, 2005), there are very few studies in Earth science that have adopted this perspective (Mills et al., 2016). Adopting an affective perspective of conceptual change, by investigating the relationship between students' interest in learning science and their conceptual change, is significant as it challenges the assumption that affective variables like interest are irrelevant to learning in a cognitively demanding discipline such as science (Zembylas, 2005).

7.5 Assertion 3: Pedagogical Considerations Warrant the Development of a Framework to Inform the use of Slowmation with School-Aged Learners.

As already indicated, there are many studies that investigate the value of slowmation for pre-service teachers' learning in science. While all of these studies advocate for the use of slowmation in teacher education courses, some also recommend the use of this instructional approach with school-aged learners. Moreover, a recent study by Paige, Bentley and Dobson (2016) reports that pre-service teachers are highly likely to implement slowmation in their future science classroom after learning about it at university. In light of the pedagogical implications presented in the previous chapter, and the lack of empirical research conducted in school contexts, these reports elicit some concern, and further consideration of how school-aged students learn with slowmation is needed.

Section 7.3 of this chapter described major differences in the way pre-service teachers and school-aged students learn with slowmation. While the translation of information between representations and pre-service teachers' cogenerative discussions have been linked to conceptual change (e.g., Hoban & Nielsen, 2014; Nielsen & Hoban, 2015), this was not observed in the current study; instead, a range of pedagogical issues appeared to inhibit opportunities for conceptual change. Specifically, students in the current study were preoccupied with the procedural aspects of constructing a slowmation; lacked motivation to understand the science content and represent it accurately; privileged and bypassed modes of representation in the construction stage; and did not have time to properly complete their slowmation due to the time consuming nature of the stop-motion animation process (Chapter 6, Section 6.4). While some of these outcomes may stem from the task worksheet, with its focus on procedures and transposition of information from the Internet (Figure 3.3), these pedagogical issues proved to be a particularly pervasive theme that arose during data analysis, and as such, they raise questions about the adequacy of current learning frameworks that inform teachers' enactment of slowmation in the classroom (e.g., the 5Rs model; Hoban & Nielsen, 2010).

In the current study, the procedural aspects of constructing a slowmation dominated students' conversations during the project. Students focused their attention on design elements such as the colour, size, sequence and timing of their slowmation. Interestingly, there was no evidence that students' preoccupation with procedural aspects was indicative of learning (e.g., using different colours to represent different layers of the Earth). This finding is epitomised in the comments made by one student during his post-intervention interview, where he indicated that he learnt a lot about "animation techniques" (Trevor). This finding is consistent with other research that found that secondary school students were more concerned with the design of the representations in their slowmation, rather than the scientific processes the students were representing (Kidman & Hoban, 2009).

It was also found that students privileged or entirely bypassed modes of representation during the modeling stage. While students privileged 'easy' modes of representation (namely, narration and text [definitions and dot point summaries]), they chose not to use other more cognitively demanding ones, such as three dimensional physical models. As a result, there were fewer opportunities for students to develop their conceptual understanding.

Together, these findings suggest that before they construct a slowmation, students require some level of representational competence beyond constructing a practise slowmation (Chapter 3, Section 3.4.1). Researchers have identified the crucial role of representational competence in developing conceptual learning (e.g., diSessa, 2004; Lehrer & Schauble, 2006a, 2006b; Lemke, 2003, 2004). As noted by Lemke (2003), drawing on Peirce (1931-1958), this competence is about knowing how to interpret and construct links between an object, its representation (whether concrete, visual or symbolic) and its meaning. This means that students need to understand the ‘partial’ nature of representations, and that generating an explanatory account involves coordinating various representations, each bringing a complementary perspective (Prain & Tytler, 2012). It is argued here that building students’ representational competence, therefore, is a necessary prerequisite for the construction of a slowmation. Representational competence could be taught explicitly during one or more science lessons, or be embedded in prior learning experiences throughout the school year or other key learning areas (e.g., Technologies). To achieve this, teachers should mediate discussions, critiques and evaluations of the use of representations (Tippett, 2016; Waldrip, Prain, & Carolan, 2010). Building students’ representational competence could alleviate students’ preoccupation with the procedural aspects of constructing a slowmation, as one would expect that their design decisions would be more informed and purposeful.

Throughout the construction process, students in the current study demonstrated waning motivation to understand the science content and represent it accurately. Instead, they were concerned with the aesthetics of their slowmation and ensuring it would be entertaining for their peers. This was evident in statements such as *‘We just want it [their slowmation] to be fun!’*. There also seemed to be a sense of complacency among students, evidenced in remarks like, *‘It [the slowmation] doesn’t need to be perfect’* and *‘It’s good enough!’*. These comments suggest that students did not value the accuracy or precision of their slowmations highly. It is possible that this was because their final product was not being assessed or used for reporting purposes. These findings raise questions about the purpose of using slowmation in the science classroom, and support the suggestion offered by other researchers that it could be used as an assessment tool to make judgments about students’ learning (Brown, 2013; Jablonski et al., 2015). This would support students to stay focused on accurately representing the desired science content.

Students’ lack of motivation to understand the science content appeared to be due, in part, to the self-directed nature of the research that they undertook prior to constructing a slowmation, as prescribed by the task worksheet (Figure 3.3). As students found locating and comprehending information a challenging task, it is likely to have impeded their willingness to come to understand the information. This is not an isolated finding, as the junior secondary school students in Jablonski and his colleague’s (2015) study reported that conducting research was the part of the slowmation construction process that students enjoyed least, indicating that they also found independently locating and comprehending information challenging. This suggests that the self-directed research task during the planning phase needs to be adapted for junior secondary school students. This could be achieved by incorporating teacher explanation into this phase. In addition to reducing the complexity of the task, this would also prevent students from consulting inaccurate representations on the Internet that reinforce further their alterative conceptions (King, 2010).

Finally, time constraints led students to rush the construction of their slowmations, which compromised the quality of the final product, and presumably, opportunities for conceptual change to occur. Students in the current study felt that constructing a slowmation “took way too long”. They found the stop-motion aspect of slowmation the most time consuming and, as such, they avoided representing information in this manner. Interestingly, time constraints have been identified as an issue in some studies undertaken with school-aged students (e.g., Hoban et al., 2007), but not in others (e.g., Jablonski et al., 2015). This seems to be due to the contrasting pedagogical purposes for the use of slowmation in science. Based upon a number of the constraints outlined in this section, it appears that setting out to construct a ‘polished’ explanatory resource is not the most effective purpose for constructing slowmation with school-aged learners; rather, slowmation could be used as a learning and discussion tool to probe students’ developing understandings during construction, and to identify and resolve students’ alternative conceptions (Kidman et al., 2012).

In summary, despite the teachable moments afforded by the construction process, it appears that the use of slowmation in the current study was only as effective as the pedagogy that supported its implementation. This highlights the need for a pedagogical framework for the use of slowmation with school-aged students. The next section will describe a framework that responds to this need.

7.6 Towards a Framework for Learning with Slowmation

Previous research has given little attention to the pedagogy that might accompany the use of slowmation in school classrooms, as is often the case with innovative approaches to student learning (Jonassen, Peck, & Wilson, 1999). While there are frameworks that describe how learning takes place throughout the construction process, there needs to be a more thorough consideration of how slowmation is actually enacted, particularly in a junior secondary school context, and the vital role of the teacher in facilitating a constructivist-oriented classroom and establishing a learning environment conducive to conceptual change. Although it is beyond the scope of this thesis to fully develop and test a complete pedagogical framework, some lessons learned from the current study have been organised into an initial, tentative framework, the LWS framework, which is now described.

As students in the current study were not accustomed to learning in the way that was required, the LWS framework is situated in a constructivist learning environment. Based upon a broad view of the pedagogical considerations outlined in the preceding subsection, it is necessary for both the teacher and students to view learning as an active process of knowledge construction and reconstruction if slowmation is to bring about students' conceptual change. In doing so, the teacher and students must be aware of, and familiar with, their role in the learning process. For the teacher, this entails eliciting students' pre-instructional ideas, providing opportunities for students' to experience new phenomena, and facilitating group and whole-class discussions (Harlen, 2009). For students, this entails discussing their own and others' ideas, using their ideas to try to understand new phenomena, modifying their ideas in light of their experiences, and developing 'bigger' ideas from 'smaller' ones (Harlen, 2009).

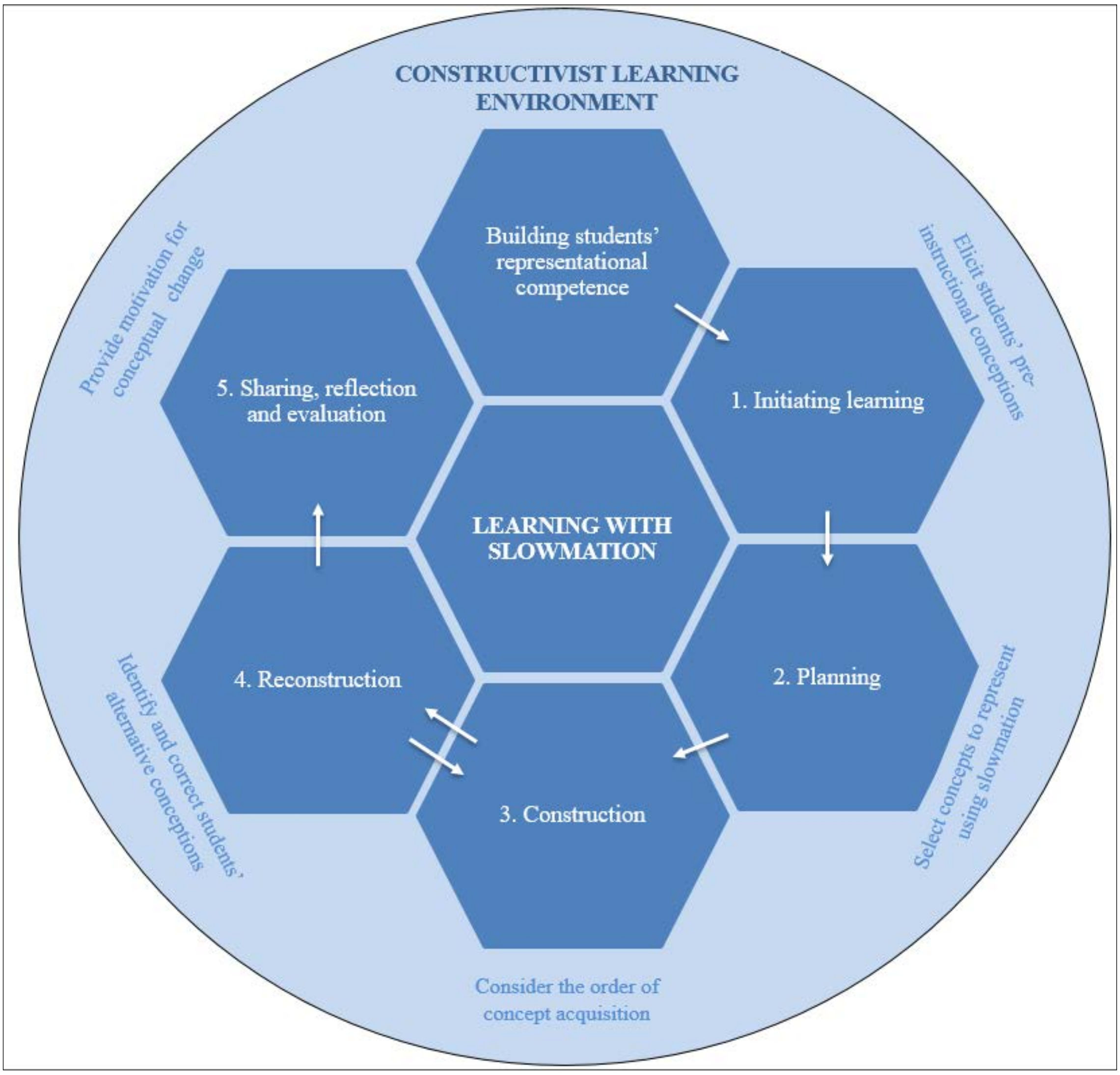

Figure 7.1. The Learning with Slowmation (LWS) framework.

Within the constructivist learning environment, the LWS framework draws from the conceptual change literature, outlined in Chapter 2, with a view to embed specific 'pedagogical actions' that contribute to students' conceptual change. It is to be noted that as an outcome of how learning proceeded in the current study, these pedagogical actions do not aim to replace students' alternative conceptions in a radical or abrupt manner, as posited by classical notions of conceptual change (Posner et al., 1982). Instead, they support the view that conceptual change is a "gradual process during which initial conceptual structures ... are continuously enriched and restructured" (Vosniadou & Ioannides, 1998, p. 1221; see Chapter 2, Section 2.3). To this end, the researcher has emphasised the role of the classroom teacher in: (1) eliciting students' pre-instructional conceptions; (2) selecting only few, key concepts to be represented using slowmation; (3) ordering concept acquisition (recall that in the current study students in the intervention group did not come to understand the geologic mechanisms driving plate tectonics, and later had difficulty coming to understand the formation of landforms at tectonic plate boundaries); (4) providing repeated knowledge enrichments by identifying and correcting students' alternative conceptions; and (5) establishing a motivating learning environment that arouses students' interest in learning about science (Vosniadou, Ioannides, Dimitrakopoulou, & Papademetriou, 2001). It is to be noted that these pedagogical actions do not strictly correspond with any given stage of the construction process, despite their positioning in the diagram.

The LWS framework itself has stages based upon the slowmation construction process identified in research conducted with pre-service teachers (Loughran, et al., 2012) and further informed by the pedagogical issues that arose in the current study. The stages of slowmation construction were adapted with a view to develop better students' representational competence, and to incorporate instruction about the science concept or process to be represented. Furthermore, the LWS framework acknowledges that students' representations are 'approximations' (Prain & Tytler, 2012), and therefore views slowmation as a learning tool rather than a means to construct a polished explanatory resource. This is demonstrated by the addition of a reflection stage, whereby students are able to share their slowmation with their peers and evaluate its explanatory adequacy. The six stages of the LWS framework, therefore, are as follows:

> *Building students' representational competence.* This stage of the framework, which precedes the formal construction stages, ensures that students have previous experience in the design and evaluation of multi-modal representations of science phenomena, beyond a 'one-off' practise, as was undertaken in the current study. This is necessary so that students' procedural decisions throughout the slowmation construction process are informed and purposeful. Representational competence could be explicitly developed during science lessons prior to the

formal construction stages, or representation construction activities could be embedded in prior learning experiences over the course of the school year.

Initiating learning. This stage of the construction process replaces independent research, which appeared to inhibit students' conceptual change in the current study. There are a number of important elements in this stage. First, students must be oriented towards the purpose of the slowmation construction task and positioned as active constructors of knowledge. In keeping with the constructivist perspective of learning adopted in this study, and the pedagogical actions identified in the LWS framework, this stage should bring students' existing conceptions to the fore. This could be achieved by student brainstorming, teacher-led questioning or the use of a diagnostic instrument such as the GeoQuiz.

Second, this stage should include one or more exploratory learning experiences that introduce students to the key science concepts to be learned. Such learning experiences should actively engage students in hands on or experiential learning, and the teacher should facilitate students' learning by helping them to test ideas or link ideas from one experience to a related one (i.e., considering the order of concept acquisition; Harlen, 2009; Vosniadou et al., 2001). This should be followed by a teacher explanation of the science content, in order to establish a common language between the teacher and students (Vosniadou et al., 2001).

Third, leading into the next stages, the teacher should make explicit the students' role in the construction process, and emphasise the importance of translating information between representations and utilising multiple modes of representation when modeling phenomena. The teacher should also emphasise the iterative nature of the planning, construction and reconstruction stages, and make explicit his/her role in checking the scientific accuracy of students' representations at each stage, and developing students' scientific conceptions by addressing knowledge gaps and misconceived knowledge.

Planning. During the planning stage, students create a storyboard that shows how they will represent the science concept or process. This involves 'chunking and sequencing' the information in frames so that it tells a story (Loughran et al., 2012). Students should also record the materials they will use in the next construction phase, and how the materials will be manipulated between each frame to represent the science concept or process and give a stop-motion animation effect.

Construction and Reconstruction. The construction and reconstruction stages in the LWS framework involve the physical construction and reconstruction of multiple representations. Notably, and most importantly due to the resilient nature of students' alternative conceptions, these stages are an iterative process, whereby the teacher and students recursively check the accuracy and adequacy of each representation (i.e., storyboard, models, still photographs and the final slowmation), refining and enriching it if necessary. In doing so, students can again be prompted to verbally question, seek evidence and make knowledge claims, to enhance further their conceptual change through cogenerative discussion (Hoban & Nielsen, 2012). These are important stages in the slowmation construction process, as students' conceptions are constructed and re-constructed alongside their physical representations in an interdependent process of knowledge enrichment. As this reconstruction requires substantial effort from students', the learning environment should motivate conceptual change by arousing students' interest and enjoyment.

Sharing, reflection and evaluation. In the final sharing and reflection stage, students' learning is enhanced further as they view their peers' slowmations and evaluate the strengths and limitations of their representations in conversation with the teacher (Prain & Tytler, 2012; Tippett, 2016; Waldrip et al., 2010). This stage should again facilitate metaconceptual awareness through the use of diagnostic assessment, with particular attention given to the resolution of any persisting alternative conceptions (Hoban & Nielsen, 2012).

As a range of accounts about how students learn with multiple representations exist (e.g., Ainsworth, 2006; diSessa, 2004; Hubber, Tytler, & Haslam, 2010; Kozma, 2003; Prain & Tytler, 2012; Tang, Delgado, & Moje, 2014), future iterations of the LWS framework could be developed further if aspects from the representations and multiple representations literature were incorporated into the framework. Of potential value to the LWS framework is the *Representational Construction Affordances framework* (Prain & Tytler, 2012) and the *Design, Functions, Tasks framework* (Ainsworth, 2006). These suggestions are discussed further in the next chapter, which provides recommendations for future research.

7.7 Limitations of the Research

Since experimental research is concerned with determining a cause-effect relationship, a quasi-experimental (non-equivalent groups) design was most appropriate in the current study. This means that the intervention and comparison groups involved in this research project were sufficiently similar that comparisons could be made between them. This approach, despite some limitations, is used extensively in science education research and has previously been widely used to evaluate the effectiveness of conceptual change instructional approaches in Earth science (Mills et al., 2016).

Numerous challenges face researchers conducting classroom-based causal effects studies. In the current study, for instance, the random assignment of students to the intervention or comparison condition was not feasible due to class timetabling constraints. Instead, classes were randomly assigned to a condition, ensuring that each teacher involved in the research project taught one intervention class and one comparison class (Randler & Bogner, 2008). Although this research design controlled teacher-related variables to some extent, ‘comparison group contamination’ (Taylor, Kowalski, Wilson, Getty, & Carlson, 2013) may have occurred. For example, the teachers may have used key elements from the intervention when teaching the comparison classes (e.g., purposefully diagnosing students’ alternative conceptions). This limitation was minimised by investigating possible class teacher and gender interaction effects that may have influenced students’ GeoQuiz scores. No significant effects were found, which suggests that the research project was implemented uniformly across the four science classes, and had a similar impact on both boys and girls. This enhanced the validity of the assertions made about students’ conceptual change and interest, based on the GeoQuiz and SILS survey results.

The mixed methods approach to data generation was another way that limitations regarding the research design were addressed. Quantitative methods were used to understand trends in the data, particularly with respect to students' conceptual change, as evidenced by their GeoQuiz scores, and their individual and situational interest in learning about Earth science, as evidenced by the SILS survey scores. Qualitative data were then used to gain a deeper understanding about the causal mechanisms underpinning students' conceptual change and change in interest, and to illuminate students' experience participating in the research project. Together, both quantitative and qualitative techniques developed a more robust insight into the value of slowmation as a conceptual change instructional approach than either approach would individually (Creswell, 2005).

As with much research bounded within a naturalistic setting, it is problematic to generalise beyond the context from which the results emerged. To some extent, this limitation was offset by providing detailed descriptions of the organisation of the study, and methods and data generation and analysis in Chapter 3. This serves to enhance the transferability of this study, or the extent to which its findings will be useful in other similar contexts. These descriptions seek to assist the reader in making an informed judgment about the transferability of the findings to their own particular context.

Developing the learning sequence for the intervention so that it was aligned closely to 'teaching as usual', presented a challenge in the current study. When conceptualising the intervention and considering what questions would guide students' independent research, it was assumed that students would spend a comparable amount of time researching each key question (Chapter 3, Section 3.4.1). Instead, students spent considerably more time researching questions about the formation of landforms at tectonic plate boundaries, as this was central to the topic of their slowmation. The implication of this was that the students in the comparison group had explicit instruction about the cause of tectonic plate movement; specifically, they participated in a hands-on experiment that demonstrated how heat causes convection. Students in the intervention group, on the other hand, glossed over this content knowledge. This reduced the comparability between conditions and is a possible explanation as to why students in the comparison group outperformed students in the intervention group, for questions on the GeoQuiz relating to the nature and movement of tectonic plates.

Although the GeoQuiz was intended to be unbiased to both the intervention and comparison conditions, the researcher was responsible for its construction. As such, there is a possibility that an unintentional bias influenced the findings of the research project (Taylor et al., 2013). The only way to mitigate against unintentional experimental bias is to have a third-party construct the relevant instrumentation. This was not feasible in the current research project, in meeting the requirements of the higher research degree sought (nor desirable, since a third-party would not be intimately familiar with the intervention and be able to design an instrument sensitive to students' conceptual change); therefore, this potential limitation was unavoidable.

In the current study, students' thinking aloud while they constructed their slowmation was one source of data used to investigate their conceptual change. Although the researcher taught the students how to verbalise their thinking prior to their involvement in the research project, it seems that this was a difficult task for the students to master in the given time. A number of rather pervasive themes arose from the analysis of the think-aloud data, and each indicated that students' dialogue was not focused on learning, but rather the design aspects of making a slowmation, and whether the slowmation was 'fun' or 'entertaining'. In part, this may have contributed to the lack of recorded instances where conceptual change (i.e., the complete replacement or modification of an existing conception) took place. In summary, while it can be assumed that conceptual change did occur, as evidenced by the results of the GeoQuiz, these instances were not captured by the think-aloud data due to the students' limited ability to verbalise their change in thinking, and the likelihood that their focus was consumed by the demands of the task at hand.

7.8 Implications of the Research

The current study extends national and international research that investigates conceptual change instructional approaches in Earth science. The results presented and discussed in this and preceding chapters (i.e., Chapters 5 and 6) suggest that students' participation in the construction of a slowmation led to statistically significant conceptual change, and enhanced their interest in learning about Earth science. There was a statistically significant relationship between these two constructs, as students' interest generated by their participation in the construction of a slowmation facilitated their conceptual change. As a culmination of the discussion thus far, the following subsections present the implications of these findings for curricular design and educational theory.

7.8.1 Implications for curricular design and implementation

The results of the current study support existing research into the affordances of student-generated animation for learning in science; namely, the value of the slowmation construction process for bringing about conceptual change. Although the slowmation construction process is well researched in pre-service teacher education contexts (Hoban et al., 2011; Hoban & Nielsen, 2012, 2013, 2014; Nielsen & Hoban, 2015), there is an absence of studies that have investigated its use with school-aged students (Brown et al., 2013; Hoban et al., 2007; Jablonski et al., 2015; Kidman & Hoban, 2009). The significant increase in students' GeoQuiz and SILS survey scores arising from this study provide an argument for the inclusion of slowmation in the junior secondary science classroom. The following implications for learning with slowmation are offered:

1. *Slowmation can complement current enactment of the curriculum with a comparable amount of learning.* In the current study, students in both condition groups (intervention and comparison) had a significant increase in their GeoQuiz scores, from pretest to posttest. This means that learning with slowmation can complement 'teaching as usual'. Given that students thoroughly enjoyed the opportunity to learn 'differently' in science, as constructing a slowmation was creative, hands-on, and engaged students in the use of digital technologies, this recommendation seems particularly warranted. This finding also responds to

concerns that teachers are underprepared to teach students about Earth's physical systems (Dawson & Moore, 2011; Lane, 2015). Slowmation can be one of several approaches used to engage students in Earth science and enhance their conceptual change, provided that it is enacted in a well-considered manner.

2. *Slowmation can be used as a learning tool to diagnose and resolve students' alternative conceptions.* As discussed in Section 7.3, students in the current study successfully represented the formation of landforms at tectonic plate boundaries in their slowmation. To do so, students translated information between multiple representations in a semiotic progression (Hoban et al., 2011). The recursive checking of information throughout this process afforded the teacher opportunities to diagnose and resolve students' alterative conceptions, which in turn led to conceptual change. As such, slowmation should be used as a learning tool in the science classroom, rather than a means to produce a polished explanatory resource. This may also alleviate the time constraints experienced by students, as they would not rush to complete their slowmation.

3. *Slowmation can be used with a view to significantly enhance students' interest in learning about science.* Several issues impacting the quality of Earth science education in Australia were identified at the onset of this thesis. One of these issues was students' disengagement with Earth science and their perception of the subject as difficult and boring (Dawson & Carson, 2013). The findings of this study support the use of slowmation for learning Earth science, as it enhanced students' conceptual development and interest.

4. Slowmation should be enacted within an established constructivist learning environment. Informed by the pedagogical considerations that arose in the current study, the value of the slowmation construction process is dependent upon the teacher and students' view of learning, which should align with constructivist principles. To enhance further opportunities for students' conceptual change, learning should be viewed as an active process of knowledge construction and reconstruction, rather than a passive accumulation of knowledge. Both the teacher and students must be aware of, and familiar with, their roles in this type of learning environment, and the teacher should employ specific pedagogical actions to facilitate students' conceptual change (Harlen, 2009; Vosniadou et al., 2001).

5. *Representational competence is an important precursor to learning with slowmation.* As discussed in Section 7.6, the LWS framework could inform the use of slowmation in the junior secondary science classroom. Ensuring that students have a moderate level of representational competence before they begin constructing a slowmation is a crucial dimension of the framework. This could mitigate students' preoccupation with the design of their representations, and their tendency to frivolously privilege and bypass modes of representation when modeling scientific phenomena.

6. *Students should be prompted to evaluate the explanatory adequacy of their slowmation after its construction.* Another crucial dimension of the LWS framework is the sharing and reflecting phase. Like the findings that arose from the current study, existing research has demonstrated that school students find translating information between representations to be a highly complex task (Ainsworth, 2006; Prain & Waldrip, 2006). It is important, therefore, that students are encouraged to construct 'approximations' (i.e., non-expert representations), and share the *reasoning* behind their design choices with their peers. This would support students' developing representational competence, but also support the assertion that such reasoning is what leads to quality learning with representations (Prain & Tytler, 2012).

7.8.2 Implications for educational theory

The results of the current study make a number of major contributions to educational theory. The nature of the research questions, which are very different to each other, means that the current study has significance to multiple fields of education. In particular, this research extends conceptual change research in Earth science education, specifically of geological phenomena; challenges traditional cognition-only notions of knowledge restructuring; and contributes to research that investigates the value of constructing multiple representations of science phenomena through student-generated slowmation. Further contributions of this thesis to educational theory are a systematic literature review on conceptual change instructional approaches in Earth science; the development and validation of a two-tiered diagnostic test instrument (i.e., the GeoQuiz); and the development of a tentative pedagogical framework for engaging school-aged learners with slowmation. Each of these major contributions will now be discussed briefly:

1. *Extends conceptual change research in Earth science education, specifically about geological phenomena.* At the onset of this thesis, it was described that students come to science classes with pre-instructional alternative conceptions that need to be better aligned with accepted scientific concepts through instruction (Ausubel, 1968; Driver & Oldham, 1986; Osborne & Freyberg, 1985; Osborne & Wittrock, 1985; Vosniadou & Brewer, 1987). While there is much evidence in the literature to suggest that students hold alternative conceptions about geological phenomena, including plate tectonics, there is a paucity of intervention studies aimed specifically at correcting these ideas (Cheek, 2010; Francek, 2013; King, 2008; Lelliott & Rollnick, 2010; Mills et al., 2016). Therefore, as articulated in Chapter 2, there is a need for research that evaluates the effectiveness of conceptual change instructional approaches in Earth science education. The findings of the current study address this gap in the literature, demonstrating that the slowmation construction process facilitates students' conceptual change. This is evidenced by a significant increase in the intervention group's GeoQuiz scores, from pretest to posttest, and the teachable moments generated by students' recursive checking of science information with the teacher.

2. *Challenges traditional notions of knowledge restructuring by adopting a cognitive-affective perspective of conceptual change.* As described in Chapter 2, conceptual change served as the theoretical framework for this study, as it remains a dominant framework regarding the development of students' naïve ideas (Duit

& Treagust, 2013; Treagust & Duit, 2008). The current study, in part, sought to challenge traditional notions of conceptual change by investigating the relationship between students' interest and conceptual change. The positive relationship arising in the present study makes a significant contribution to theory. As mentioned in Chapter 2, the CRKM (Dole & Sinatra, 1998) is one of very few cognitive-affective conceptual change models. It describes the interaction between a learner's 'characteristics' and a new concept and pays particular attention to the influence of motivational variables, including interest, on conceptual change. Notwithstanding the contribution of the CRKM to conceptual change research, in the decade since its publication, it is yet to be tested and validated by empirical research. Only one recent study has embarked on this agenda, providing evidence that students' need for cognition (i.e., the tendency to engage in and enjoy effortful cognitive activities), goal orientation, and motivation predicted students' conceptual change (Taasoobshirazi & Sinatra, 2011). The findings of the current study contribute to the validation of the CRKM by providing evidence that, for the students in this study, interest (both individual and situational) is a significant predictor of conceptual change. Other constructs from the CRKM such as self-efficacy, or new constructs that have been researched in science education such as emotion, could be tested and validated in the future with the aim of developing a more complete and contemporary cognitive-affective model of conceptual change.

3. *Contributes to research that investigates the value of constructing multiple representations of science phenomena through student-generated animation.* A review of the literature on the learning potential of student-generated animations, presented in Chapter 2, revealed a paucity of research in this field. A number of studies noted the educational value of students creating animations in Chemistry (Schank & Kozma, 2002; Stieff & Wilensky, 2003; Wilder & Brinkerhoff, 2007; Wu et al., 2001), while another has examined the educational value of creating animations in Mathematics (Hubscher-Younger & Hari Narayanan, 2008). In all of these studies, students used specially designed animation software. Student-

generated animations that do not require specially designed software, such as slowmation, have been researched more recently in pre-service teacher education; however, there remains the need to investigate “how learners in different contexts … make multimodal animations to represent science concepts” (Hoban et al., 2011, p. 1004). The findings of the current study, therefore, respond to this need, and also to the broader need for research on effective conceptual change instructional approaches (Treagust & Duit, 2008). As discussed in the previous subsection, the findings of the current study have substantial implications for science teachers and teacher educators, which are crucial to narrowing the theory-practice gap in relation to conceptual change research (Treagust & Duit, 2008).

4. *Establishes the need for conceptual change instructional approaches in the Earth science discipline through a systematic review of the literature.* Chapter 2 presented a systematic literature review of conceptual change instructional approaches used in the Earth and space science disciplines. In total, 52 studies were identified and analysed. The analysis focused on the general characteristics of the research, the conceptual change instructional approaches that were used, and the methods employed to evaluate their effectiveness. This literature review presents a significant contribution to the existing body of research in this field, as it integrates findings from multiple approaches and contexts, and makes recommendations for future research.

5. *Contributes a two-tiered diagnostic instrument, the GeoQuiz, which measures students’ alternative conceptions about plate tectonics.* The current study used a two-tiered multiple-choice test in order to evaluate students’ conceptions pre- and post-intervention. As there were no existing test instruments relevant to the science concepts underpinning the *Changing Earth* unit of work, the researcher developed and validated the GeoQuiz. The contribution of the GeoQuiz to existing diagnostic test instruments is significant given that appropriate assessment tools have to be readily available for use by classroom teachers in order to facilitate students’ understanding of scientific concepts and gauge the

effectiveness of classroom instruction (Treagust, 2006). The GeoQuiz is currently the only two-tiered diagnostic test instrument to assess geological concepts relevant to the Earth science discipline (see Treagust, 2006).

6. *Contributes a tentative pedagogical framework to support the use of slowmation, or other representation construction activities, with school-aged learners.* A number of pedagogical issues that appeared to inhibit opportunities for students' conceptual change were discussed in Section 7.5. The prevalence of these issues indicates that a pedagogical framework is required to inform teachers and teacher educators about how to best use slowmation with school students. This thesis presented a tentative pedagogical framework, the LWS framework, in Section 7.6. While this framework is specific to the slowmation construction process, its applicability could be extended to other representation construction activities, including those that require the use of technology. As discussed, this framework situates the construction process in a constructivist learning environment and promotes conceptual change by emphasising the teacher's role in learning as students physically and cognitively construct and reconstruct their existing ideas. Furthermore, the framework adapts the stages of slowmation construction from pre-service teacher education contexts to develop better school students' representational competence, and to incorporate instruction about the science concept or process to be represented. In addition, the LWS framework acknowledges that students' representations are 'approximations' (Prain & Tytler, 2012), and therefore views slowmation as a learning tool rather than a means to construct a polished explanatory resource. This is demonstrated by the addition of a reflection stage, whereby students are able to share their slowmation with their peers and evaluate its explanatory adequacy.

7.9 Chapter Conclusion

This chapter has discussed the results presented in earlier chapters, the implications of the findings for curricular design and implementation, and educational theory, and the limitations of the study. Three assertions were synthesised from the results of the quantitative and qualitative data generated in this study, in response to the research questions: the construction of a slowmation significantly enhanced students' conceptual change as it afforded teachable moments; students' interest and enjoyment, generated by their participation in constructing a slowmation, facilitated conceptual change; and pedagogical considerations warrant the development of a learning framework to inform the use of slowmation with school-aged learners.

Overall, this study has made a significant contribution to educational theory and practice. In regards to Research Questions 1 and 2, it was found that students' participation in the construction of a slowmation significantly enhanced their conceptual change, as it provided teachable moments wherein students' alternative conceptions were identified and corrected by the teacher. This finding complements existing research that demonstrates the positive impact of slowmation on students' learning. In contrast to existing research, however, the teacher played a crucial role in facilitating students' conceptual change. Rather than students' conceptual change arising from the construction of multiple representations or cogenerative discussion amongst themselves, which has been reported in pre-service teacher education contexts, the teacher checked the accuracy of students' representations and prompted them to consider their explanatory value. These teachable moments added scientific 'elements' to students existing conceptions, as evidenced by the think-aloud data, which gradually culminated in conceptual change, as evidenced by the change in students' GeoQuiz scores. This finding responds to calls for further research on the value of slowmation for learning in science (Hoban et al., 2011; Hoban & Nielsen, 2013, 2014) and the evaluation of instructional approaches that target students' misconceived knowledge about Earth science phenomena (Francek, 2013; King, 2008; Lelliott & Rollnick, 2010; Mills et al., 2016).

In regards to Research Question 3, it was found that students' interest in learning science was significantly greater if they participated in the construction of a slowmation, and students' interest was found to be a significant predictor of their conceptual change. This finding extends the limited research that investigates whether students' interest may bring about conceptual change and helps to clarify the opposing results reported to date. More broadly, by adopting a cognitive-affective perspective of conceptual change that considers affective variables, like interest, as causal mechanisms for conceptual change, this research has challenged traditional notions of knowledge restructuring in response to recommendations for new research in this field to do so (Pintrich et al., 1993; Sinatra, 2013; Tyson et al., 1997; Venville & Treagust, 1998).

An unexpected finding from the current study was that several pedagogical issues arose during the implementation of the research project, that appeared to constrain opportunities for conceptual change. This finding, although not responding directly to a research question, demonstrates the limitations of current learning frameworks that inform the use of slowmation, and the need for a more well-considered and nuanced framework that is specific to learning with slowmation in a junior secondary school context. Although it was beyond the scope of this thesis to fully develop and test a complete pedagogical framework, some lessons learned from the current study have been organised into the LWS framework, an initial, tentative framework for further development in future research. Concluding remarks for this study, which include recommendations for future research arising from this thesis, are presented in the next chapter.

CHAPTER EIGHT: CONCLUSION

This thesis has made major contributions to multiple fields of educational practice and theory. In response to a range of challenges impacting the quality of Earth science education in Australia, as articulated in Chapter 1, this study investigated how constructing a slowmation influenced middle school students' conceptual change, and the relationship between students' interest, generated by the construction process, and their conceptual change. In doing so, the study challenges classical notions of conceptual change theory by adopting a cognitive-affective perspective; extends conceptual change research in Earth science education, specifically about geological phenomena; and contributes to research that investigates the value of student-constructed slowmation. The study's findings indicate that slowmation can complement current enactment of the curriculum with a comparable amount of learning, and can be used with a view to significantly enhance students' interest in learning about science and geology. Notwithstanding the significance of this finding, a range of pedagogical issues arose throughout the slowmation construction process, which suggest that a more thorough consideration of the supporting pedagogy is required. As such, the present study culminated with the presentation of the LWS framework, which integrates conceptual change literature with the study's findings to develop a pedagogically robust view of learning with slowmation.

In the current study, all students in the research project, regardless of condition, had a significant increase in their GeoQuiz scores from pretest to posttest. This means that the construction of a slowmation had significant effect on students' conceptual change. Importantly, this finding suggests that slowmation can complement schools' current enactment of curriculum with a comparable amount of learning. This finding supports other research on the positive effects of school students learning with slowmation (Brown et al., 2013; Hoban et al., 2007; Jablonski et al., 2015; Kidman & Hoban, 2009). One point of difference, however, was the researcher's choice to audio-record students as they verbalised their thinking during the construction process. While this methodological decision was made with a view to provide a more fine-grained and nuanced understanding about how the slowmation construction process facilitated students' conceptual change, this aim was not realised in full due to a range of pedagogical issues that arose over the course of the study.

In investigating how constructing a slowmation influenced the conceptual change of the students in this study, it was found that the slowmation construction process afforded teachable moments wherein the teacher identified and corrected students' alternative conceptions. The teachable moments were a product of the students' recursively checking the accuracy of their information with the teacher as they translated information from one representation to another in a semiotic progression (Hoban et al., 2011). Although no instances of conceptual change *per se* were identified, when this finding is considered alongside the increase in students' GeoQuiz scores, it seems that the knowledge enrichment that accompanied repeated additions of scientific 'elements' to students' existing conceptions culminated in conceptual change. As research on the value of school students learning with slowmation is scarce, this finding was considered with reference to research conducted with pre-service teachers.

It seems that pre-service teachers and school-aged students learn with slowmation differently. While the pre-service teachers in earlier studies (e.g., Hoban & Nielsen, 2014) demonstrated a strong desire to understand the science content, and actively check the accuracy of their information on the Internet, the Year 9 students in the current study appeared to lack the motivation to understand the science content independently, and to represent it accurately in their slowmation. In pre-service teacher education contexts, the transformation of information between modal representations has been linked to conceptual change, whereas in the current study, students privileged 'easy' modes of representation such as narration and therefore did not have multiple opportunities to review their knowledge. Furthermore, research conducted with pre-service teachers indicates that the co-generative discussion amongst themselves is sufficient to bring about conceptual change. In the current study, however, the classroom teacher was solely responsible for identifying and correcting students' misconceived knowledge. Finally, unlike pre-service teachers, who are able to construct a slowmation in a short amount of time, students in the current study could not complete their slowmation in the allocated four 70-minute science lessons.

These differences indicate that greater attention to the pedagogy surrounding the use of slowmation with school students is needed. First, and most importantly, the value of the slowmation construction process is dependent upon the teacher and students' view of learning, which should align with constructivist principles. Second, students need a moderate level of representational competence before they engage in the construction of a slowmation in order to alleviate students' preoccupation with the design of their representations, and their tendency to privilege and bypass modes of representation when modeling scientific phenomena. Third, slowmation should be used as a learning tool in the science classroom, rather than a means to produce a polished explanatory resource. In line with this perspective, students should be encouraged to evaluate the explanatory adequacy of their slowmation after the construction process.

The LWS framework, although tentative, responds to these assertions. The framework is situated within a constructivist learning environment wherein pedagogical actions likely to bring about students' conceptual change are given explicit attention. It also incorporates a pre-construction stage that aims to build students' representational competence in prior learning experiences, and a post-construction stage wherein students' learning is enhanced further as they view their peers' slowmations, and evaluate the strengths and limitations of their representations in conversation with the teacher.

In investigating the relationship between students' interest and their conceptual change, this study found that students' interest in learning about science, and about geology topics in particular, was significantly greater if they participated in the construction of a slowmation, compared to teaching as usual. In addition, for students who participated in the construction of a slowmation, their overall interest was found to be a significant predictor of conceptual change. This finding challenges traditional notions of conceptual change by demonstrating that there is a positive relationship between students' interest and their conceptual change. Furthermore, this finding has implications for teachers, who can create learning environments conducive to conceptual change by using innovative and engaging instructional approaches that capture students' interest in learning about science (i.e., triggered-SI).

A number of directions for future research can be drawn from the current study. As articulated at the onset of this thesis, there are few studies that explore school students' alternative conceptions of Earth science phenomena. Continued research into students' conceptions, including how scientific and alternative conceptions may arise, is required in order to develop conceptual change instructional approaches. Research of this nature can inform professional development for teachers on effective implementation of Earth science curricula, and could be used to evaluate instructional approaches. Research of this nature is particularly timely in Australia, as a new Earth and Environmental Science curriculum is being implemented in senior secondary schools (ACARA, 2016). Examples of how this paucity of research is being addressed include the identification of students' alternative conceptions about groundwater (Reinfried, 2006), cyclones (Lane & Coutts, 2012) and desertification (Schubert, 2014).

Research on teachers' conceptions of Earth science phenomena is also required so that common alternative conceptions can be addressed through professional development. This is especially important given that teachers can inadvertently be a source of students' alternative conceptions (King, 2000), and some Earth science teachers do not see value in extensive and in depth content knowledge (Lane, 2015). An example of recent research that meets this aim investigated teachers' understanding of cyclones (Lane, 2011). Of concern is that teachers held a range of alternative conceptions and lacked knowledge of underlying scientific concepts. Research of this nature is especially warranted in the Earth science discipline, given that many Australian teachers are underprepared to teach in this area due to a lack of appropriate teacher education in this field (Dawson & Carson, 2013; Stoltman et al., 2015).

Given that a significant development in the field of conceptual change research is the 'warming trend' that describes the move away from cognition only models of conceptual change (Sinatra, 2005), further research on the relationship between affective variables and conceptual change is warranted. Further research can focus on affective variables such as achievement goals, interest and enjoyment, self-efficacy and emotions (Sinatra & Mason, 2013). Moreover, certain combinations of these variables can be considered, in light of emerging research that suggests they should not be considered in isolation (Cordova et al., 2014; Linnenbrink-Garcia at al., 2012). Finally, as only few attempts have been made at developing a cognitive-affective model of conceptual change (e.g., CRKM model; Dole & Sinatra, 1998), further research with the aim of developing a more complete and contemporary cognitive-affective model of conceptual change would be particularly valuable.

Strengthening the internal reliability of the test instrument used in this study, as measured by Cronbach's alpha coefficient, is another direction for future research. This could be achieved by adding items of a similar quality to the test instrument. The researcher has calculated that 21 items (i.e., an additional 11 items) would be needed for an even more acceptable internal reliability of .60 (Nunally, 1978). A strengthened version of the test instrument could be used in future research to diagnose students' alternative conceptions across multiple year levels or evaluate the effectiveness of another targeted intervention.

The development of the LWS framework presents a significant and potentially fruitful avenue for future research arising from this study. Repeating the current study with greater attention to the nature of the classroom learning environment and the role of the classroom teacher, as informed by the framework, is one such avenue for future research. Also, as previously mentioned, of potential value to the LWS framework is Prain and Tytler's (2012) *Representational Construction Affordances* framework. This framework suggests that student-generated representations, such as slowmation, have affordances for students' learning that can be conceptualised as semiotic, epistemic and epistemological (Prain & Tytler, 2012). The LWS framework, then, could be further developed to consider how students' learning is scaffolded among these interdependent domains. More practically, aspects of the *Design, Functions, Tasks* framework (Ainsworth, 2006) could be integrated within the LWS framework to further enhance teachers' consideration of the pedagogical demands of a multiple representations task such as constructing a slowmation. For instance, the *Design, Functions, Tasks* framework (Ainsworth, 2006) prompts teachers' consideration of design principles (e.g., the number, sequence and form of representations), students' meta-representational competence (i.e., their ability to understand and construct representations), and whether the characteristics of a given representation facilitate or constrain students' learning.

In addition to the important contribution that this study makes to informing effective practice in Earth science education, the multi-faceted nature of the research also represents a significant contribution in other fields of educational theory. In particular, this research challenges cognition-only notions of knowledge restructuring by adopting an affective perspective of conceptual change, and extends research that investigates the value of constructing student-generated slowmation. While a number of directions for future research have been suggested in this chapter, including enhancing the LWS framework, it is clear that the slowmation construction process has the potential to bring about school students' conceptual change whilst also sparking their interest in learning about science and geology. This is an important and timely contribution to the development of Earth science education in Australia.

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Appendices

Appendix A: Information Sheet and Consent Forms

REPRESENTING EARTH SCIENCE CONCEPTS THROUGH SLOWMATION: INFLUENCES ON MIDDLE SCHOOL STUDENTS' CONCEPTUAL CHANGE

This research project is being conducted by Reece Mills and will contribute to his PhD at James Cook University. The aim of the research project is to engage Year 9 science students in the creation of a stop-motion animation, or slowmation, as a means of developing their understanding of Earth science concepts. Students will manipulate a range of materials to represent an earth science concept. They will photograph each manipulation using the *MyCreate* application, display the photographs at five frames per second to create an animation, and add narration that explains the concept. The project will extend research that suggests student-generated animation is an effective way of learning science.

The research project will be carried out in three stages. During ***Stage One (Term 1, 2015)***, students from Year 9 science classes may be invited to participate in ***interviews*** about their understanding of Earth science concepts. Interviews will be conducted during class time and will take approximately 15 minutes.

During ***Stage Two (Term 1, 2015)***, Year 9 science classes will be taught how to create a slowmation. In this stage of the research project, students may be ***audio recorded*** during class time and may be invited to participate in an ***interview*** about their learning that will take approximately 15 minutes.

Year 9 science classes will again create slowmations during ***Stage Three (Term 2, 2015)***. Participation in this stage may involve the completion of a ***multiple-choice test and questionnaire***, participation in ***interviews*** about their learning, and ***audio-recordings*** during class. Slowmation representations from this stage will be ***kept by the researcher and analysed for evidence of learning***. The multiple-choice test and questionnaire will be completed in class time before and after students create their animation and will each take about 10 minutes. Interviews will be completed during class time and will take approximately 15 minutes.

Participation is voluntary and students can stop taking part in the study at any time without explanation or disadvantage.

Information arising from the research project will be used in research publications and reports. **Students will not be identified in any way in these publications, as any information that is gathered throughout the research project will be anonymous and confidential.**

We ask that you sign a written consent form (enclosed) to confirm your agreement to participate in the research project.

If you have any questions about the study please contact Reece Mills or Professor Brian Lewthwaite, whose contact details are listed below.

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Finally, if you have any concerns regarding the ethical conduct of the research project, please contact:

Human Ethics, Research Office
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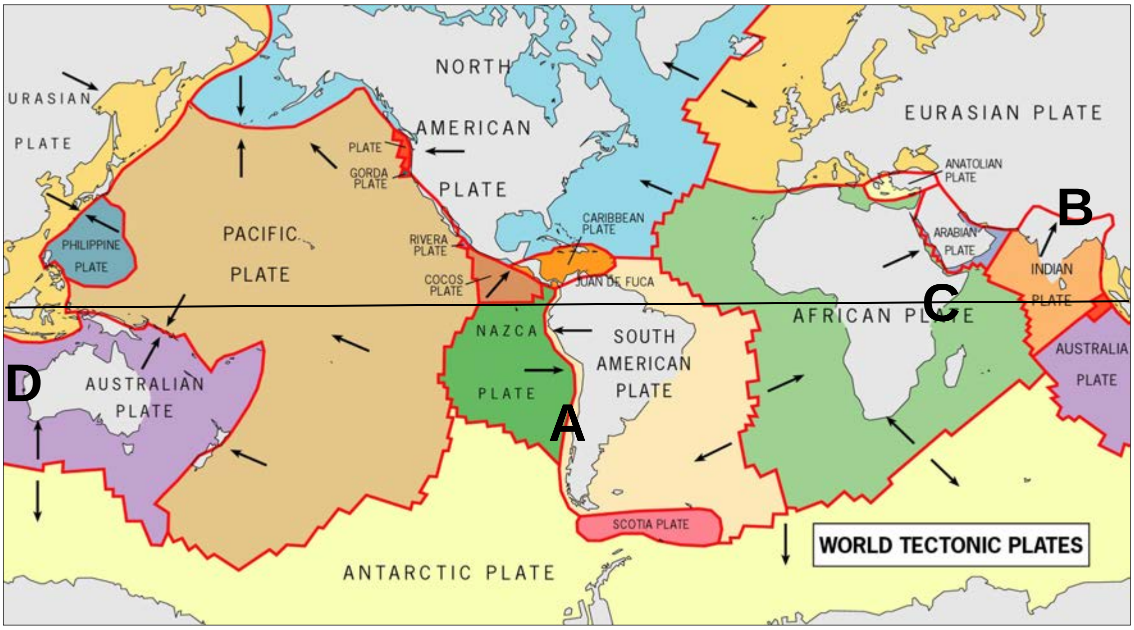
Appendix B: The GeoQuiz

Use the map below to answer questions 1-3.



Question 1

On the map, which letter is located at a tectonic plate boundary?

A. A
B. A and B
C. C
D. C and D

The reason for my answer is because:

1. Tectonic plate boundaries are found at the edges of continents
2. Tectonic plate boundaries are found at the equator
3. Tectonic plate boundaries only occur where continents meet oceans
4. Tectonic plate boundaries are where two tectonic plates meet
5. ____

   ____

Question 2

On the map, which letter is located in an area where volcanoes are likely to occur?

A. A
B. B
C. C
D. D

The reason for my answer is because:

1. Volcanoes are located in places that have a high temperature, like at the equator
2. When two continental tectonic plates push together, both plates are pushed upward to form volcanoes
3. When an oceanic tectonic plate and a continental tectonic plate push together, the oceanic plate material is pushed downward and melts to form volcanoes
4. There is a mountain range located here, and all mountains are volcanoes
5. ____

   ____

Question 3

On the map, which letter is located in an area where mountains are likely to occur?

A. A
B. A and B
C. C
D. C and D

The reason for my answer is because:

1. Mountains are formed when the edges of two tectonic plates are pushed upward
2. Mountains are formed when the edge of one tectonic plate is pushed downward, and one tectonic plate is pushed upward
3. Mountains are formed when both 1 and 2 occur
4. Mountains are formed when pieces of rock pile up
5. ____

   ____

Question 4

Which of the following are a part of Earth's tectonic plates?

A. Continents but not the ocean floor
B. The ocean floor but not continents
C. Neither continents nor the ocean floor
D. Both continents and the ocean floor

The reason for my answer is because:

1. Earth's tectonic plates are located deep within the Earth and are not exposed at the surface
2. The outer layer of the Earth, including continents and the ocean floor, consists of separate tectonic plates
3. ____

   ____

Question 5

What causes Earth's tectonic plates to move?

A. Gravity
B. Heat
C. Earth's movement
D. Ocean currents

The reason for my answer is because:

1. Earth's spin on its axis causes tectonic plates to move
2. Molten rock in Earth's mantle boils and the bubbles cause tectonic plates to move
3. Molten rock in Earth's mantle rises and falls creating convention currents that cause tectonic plates to move
4. Earth's oceans push against continents and cause tectonic plates to move
5. ____

   ____

Question 6

Earth's continents were joined in one supercontinent:

A. Two hundred years ago
B. Two thousand years ago
C. Two million years ago
D. Two hundred million years ago

The reason for my answer is because:

1. Earth's continents and ocean basins move a few centimeters each year
2. Earth's continents and ocean basins move a few centimeters over hundreds of years
3. Earth's continents and ocean basins move a few centimeters over millions of years
4. The layer beneath Earth's plates moves very rapidly
5. ____

   ____

Question 7

If a tectonic plate is made of continental plate material and another is made of oceanic plate material, what will happen as they push together?

A. The edges of both tectonic plates will be pushed upward
B. The edge of one tectonic plate will stop moving and the edge of the other tectonic plate will be pushed upward
C. The edge of one tectonic plate will be pushed downward and the edge of the other tectonic plate will be pushed upward
D. Both tectonic plates will stop moving

The reason for my answer is because:

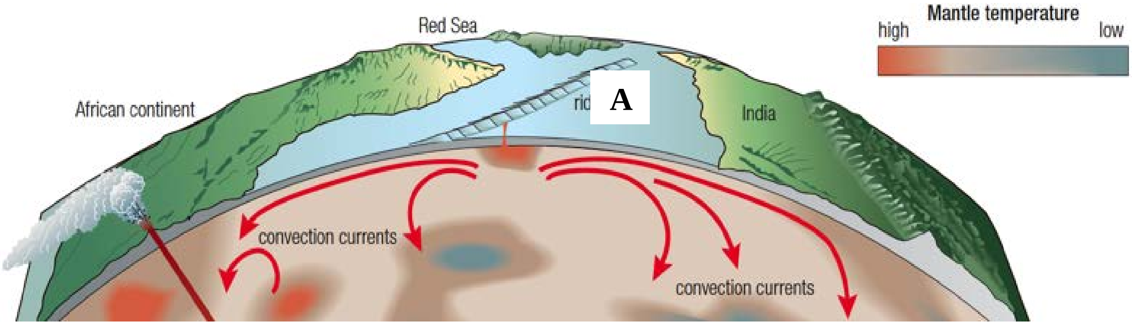
1. When two tectonic plates push together for millions of years, the larger tectonic plate is pushed upward
2. When two tectonic plates push together for millions of years, the faster moving tectonic plate is pushed upward
3. When two tectonic plates push together for millions of years, the more buoyant tectonic plate is pushed upward
4. When two tectonic plates push together for millions of years, the tectonic plate that is positioned the highest is pushed upward
5. ____

   ____

Question 8

What type of landform is located at the letter A the diagram below?

A. Trench
B. Mid-ocean ridge
C. Canyon
D. Mountain



The reason for my answer is because:

1. When two tectonic plates separate, an empty gap forms between them
2. When two tectonic plates separate, loose rock fills the gap that forms between them
3. The continents are separated and oceanic crust material is formed between them
4. A trench forms when oceanic crust material separates

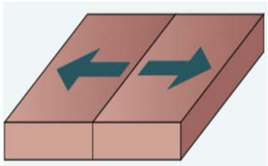
5. ____

____

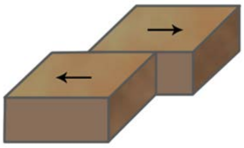
Question 9

Which diagram below represents how an earthquake may occur?

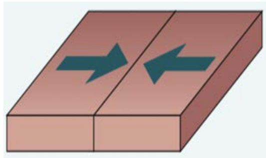
A.



B.



C.



The reason for my answer is because:

1. Earthquakes occur at plate boundaries when two tectonic plates crash together
2. Earthquakes occur at plate boundaries when two tectonic plates suddenly move apart
3. Earthquakes occur along breaks in rock where one side moves
4. Earthquakes occur when two tectonic plates rub together

5. ____

____

Appendix C: The SILS Survey

Q1 How much interest do you have in learning about the following science topics?

(Please tick only one box in each row)

	High Interest	*Medium Interest*	*Low Interest*	*No Interest*
a) Topics in physics	☐ $_4$	☐ $_3$	☐ $_2$	☐ $_1$
b) Topics in chemistry	☐ $_4$	☐ $_3$	☐ $_2$	☐ $_1$
c) The biology of plants	☐ $_4$	☐ $_3$	☐ $_2$	☐ $_1$
d) Human biology	☐ $_4$	☐ $_3$	☐ $_2$	☐ $_1$
e) Topics in astronomy	☐ $_4$	☐ $_3$	☐ $_2$	☐ $_1$
f) Topics in geology	☐ $_4$	☐ $_3$	☐ $_2$	☐ $_1$
g) Ways scientists design experiments	☐ $_4$	☐ $_3$	☐ $_2$	☐ $_1$

Q2 How much do you agree with the statements below?

(Please tick only one box in each row)

	Strongly agree	*Agree*	*Disagree*	*Strongly disagree*
a) I generally have fun when I am learning Earth science topics	☐4	☐3	☐2	☐1
b) I like reading about Earth science	☐4	☐3	☐2	☐1
c) I am happy doing Earth science problems	☐4	☐3	☐2	☐1
d) I enjoy acquiring new knowledge in Earth science	☐4	☐3	☐2	☐1
e) I am interested in learning about Earth science	☐4	☐3	☐2	☐1

Q3 Think about your experience *this term* while answering the questions below. How much do you agree with the statements below?

(Please tick only one box in each row)

	Strongly agree	*Agree*	*Disagree*	*Strongly disagree*
a) My science teacher is exciting	☐4	☐3	☐2	☐1
b) When we do science, my teacher does things that grab my attention	☐4	☐3	☐2	☐1
c) My science class is often entertaining	☐4	☐3	☐2	☐1
d) My science class is so exciting it’s easy to pay attention	☐4	☐3	☐2	☐1

Q4 Think about your experience *this term* while answering the questions below. How much do you agree with the statements below?

(Please tick only one box in each row)

	Strongly agree	*Agree*	*Disagree*	*Strongly disagree*
a) What we are learning in science is fascinating to me	☐4	☐3	☐2	☐1
b) I am excited about what we are learning in science	☐4	☐3	☐2	☐1
c) I like what we are learning in science	☐4	☐3	☐2	☐1
d) I find the science we do in class interesting	☐4	☐3	☐2	☐1

Q5 Think about your experience *this term* while answering the questions below. How much do you agree with the statements below?

(Please tick only one box in each row)

	Strongly agree	*Agree*	*Disagree*	*Strongly disagree*
a) What we are studying in science is useful for me to know	☐4	☐3	☐2	☐1
b) The things that we are studying in science are important to me	☐4	☐3	☐2	☐1
c) What we are learning in science can be applied to real life	☐4	☐3	☐2	☐1
d) We are learning valuable things in science	☐4	☐3	☐2	☐1

Appendix D: Coding Catalogue

Code name	Definition	Sample quotations	
CONTENT	Students discuss the content of their slowmation.	Sam:	I think we should say what tectonic plates are.
COLOUR	Students discuss the colour of their slowmation.	Lilly:	Grab all different colours of the whiteboard markers!
FUN/ENTERTAINMENT	Students reference their desire to produce a slowmation that is fun or entertaining.	Lilly:	We just wanted it *[the slowmation]* to be fun.
GESTURE	Students or the teacher uses hand gestures to communicate an explanation to their peers.	Teacher:	So when they come together, one goes like *this* and the other one pushes up like *this*.
HARD TO REPRESENT	Students understand the science content but are experiencing difficulty representing it accurately.	Melanie:	I'm trying to make it obvious that they're moving but it's not really working ((laugh)).
HELP	Students ask their peers or the teacher for help.	Sarah:	OK what do I search up on Google?
INFORMATION CHECKING	Students check the accuracy of the information included in their slowmation by consulting their peers, the teacher, or the Internet.	Lilly:	Was it called continental drift when all the continents split up?
INFORMATION SEEKING	Students search for information using the Internet.	Ellie: Louisa: Ellie:	Does it *[the magma at a mid-ocean ridge]* go out that much though? Probably. Check that picture.
KNOWLEDGE SHARING	Students share their prior knowledge or the information they have found on the Internet with each other.	Jason:	Oh wow! Mount Everest is 8km high!
LACK OF MOTIVATION	Students demonstrate a lack of motivation to either (1) understand the science content and/or (2) represent it accurately in their slowmation.	Louisa:	She *[the teacher]* won't see it *[the research notes]*. It doesn't really matter if you don't understand what it's saying.

MATERIALS	Students discuss the materials they will use in their slowmation.	Researcher:	What are you going to use for the plates? Paper?
MISCONCEIVED KNOWLEDGE	Misconceived knowledge (either a specific alternative conception or a flawed mental model) evidenced in students' dialogue.	Will:	The volcano builds and erupts and then turns into a mountain.
PROGRESS CHECK	Students check on their peers' progress completing a task.	Melanie: Sam:	What're you up to? I'm up to question three.
REPRESENT (DRAWING)	Students discuss how they will represent the science content using a drawing.	Michael:	Get an image up of a tectonic plate and we'll just do a diagram.
REPRESENT (MODEL)	Students discuss how they will represent the science content using a model.	Jason: Ellie: Jason:	You can use them as tectonic plates. What? The sponges.
REPRESENT (NARRATION)	Students discuss how they will represent the science content using narration.	Sam: Melanie:	We could have somebody narrating that? That's a good idea.
REPRESENT (PHOTO)	Students discuss how they will represent the science content using a photograph.	Teacher: Sam:	What do you need to use the Internet for? We're going to search up a picture of the plates to use.
REPRESENT (PRIVILEGE)	Students favor one mode of representation over another, or bypass a mode of representation altogether.	Lilly: Sarah:	I just wanted it to be simple. I know. After this we'll just do drawings and writing.
REPRESENT (TEXT)	Students discuss how they will represent the science content using text.	Ellie:	We need to label it to say Pangaea.
ROLES	Discussion about group members' responsibilities during the construction process.	Louisa: Ellie:	Do you want to talk? No. We could take turns talking?
SEQUENCE	Students discuss the order of information in their slowmation.	Paul: Jackson:	Should we include some of the mountain ranges that have been formed by these? Yeah.

		Teacher: Paul:	Are you going to put that early or later in the piece? Later on.
SIZE	Students discuss the size of their representations in their slowmation.	Will:	They’re all the same size. I made sure they’re all three centimetres.
TASK CLARIFICATION	Students ask their peers or the teacher to clarify an aspect of the construction process.	Will:	So in this task… What is the task exactly?
TEACHER GUIDANCE	The teacher or researcher answers a content-related question from students or prompts students to change incorrectly represented science content in their slowmation.	Teacher:	So how are we going with our research here?
TIME CONSTRAINTS	The students or teacher voice aloud their concerns that they do not have enough time to construct the slowmation.	Teacher:	You need to hurry up. You’re not going to get this done.
TIMING	Discussion about the number and/or timing of frames in the slowmation.	Zach: Trevor:	Should we do that for two sequences so that it actually stays there for longer? Yeah.

Appendix E: Validation Grid for the GeoQuiz

Please indicate whether these statements are representative of knowledge embedded in the Department of Education and Training's C2C unit *Changing Earth*.

(*Please tick to indicate.*)

Plate tectonics

		Yes	No
PT1	The Earth's structure includes the crust, upper mantle, lower mantle, outer core, and inner core.	☐	☐
PT2	The lithosphere is the solid outer layer of the Earth made up of the crust (continents and ocean basins) and upper mantle.	☐	☐
PT3	The asthenosphere is the partially molten zone in the upper mantle immediately below the lithosphere.	☐	☐
PT4	The lithosphere is cracked in places, broken up into tectonic plates.	☐	☐
PT5	Possible driving forces behind plate movement include convection in the asthenosphere and the pull effect of subducting lithosphere.	☐	☐
PT6	At divergent plate boundaries lithospheric plates move apart.	☐	☐
PT7	A seafloor spreading ridge is the most common type of divergent plate boundary and is where new oceanic lithosphere is created.	☐	☐
PT8	Seafloor spreading ridge segments are offset by transform faults.	☐	☐
PT9	A continental rift is a type of divergent plate boundary.	☐	☐
PT10	At convergent plate boundaries lithospheric plates move toward each other.	☐	☐
PT11	A mountain range is a landform that may be formed at a convergent plate boundary.	☐	☐
PT12	A subduction zone occurs at convergent plate boundaries where one tectonic plate is pushed under another.	☐	☐
PT13	Average rates of plate movement are two to three centimeters per year.	☐	☐

Continental drift

		Yes	No
CD1	Continental drift suggests that Earth's continents move and were once joined in one supercontinent called Pangaea.	☐	☐
CD2	There are multiple sources of evidence that support continental drift, including matching continental geology (rock types, rock ages, fossils, ore deposits, and so on), paleomagnetism, and polar-wander curves.	☐	☐
CD3	Continental drift is a process that is measured in geological time, occurring over the past 200 million years.	☐	☐

Volcanic activity occurring at plate boundaries

		Yes	No
VE1	Volcanoes can form at divergent plate boundaries where magma wells up from the asthenosphere.	☐	☐
VE2	Volcanoes (fissures) can form along continental rifts.	☐	☐
VE3	Isolated areas of volcanic activity not associated with plate boundaries are called hot spots and are likely the result of particularly warm material at the base of the mantle.	☐	☐

Earthquakes and locating the epicenter of an earthquake

		Yes	No
VE1	The stresses involved in convergence and subduction give rise to earthquakes.	☐	☐
VE2	The point on a fault at which the first movement occurs during an earthquake is called the focus.	☐	☐
VE3	The point on Earth’s surface directly above the focus is called the epicentre.	☐	☐
VE4	When an earthquake occurs, it releases the stored-up energy in seismic waves.	☐	☐
VE5	P waves are compression waves. That is, as P waves travel through matter, it is alternatively compressed and expanded.	☐	☐
VE6	S waves are shear waves, involving side-to-side motion.	☐	☐
VE7	Both types of body waves are detectable using a seismograph.	☐	☐
VE8	P waves travel faster through rock than S waves and are therefore detected first.	☐	☐
VE9	The difference in arrival time between the first P and S waves is a function of distance to the earthquake’s epicentre.	☐	☐
VE10	The amount of ground movement is related to the magnitude of the earthquake.	☐	☐
VE11	The magnitude of an earthquake is most commonly reported using the Richter scale.	☐	☐
VE12	A Richter magnitude number if assigned to an earthquake based on an adjusted ground displacement measured by a seismograph.	☐	☐
VE13	The Richter scale is logarithmic.	☐	☐
VE14	Intensity is a measure of an earthquake’s effects on humans and on surface features.	☐	☐
VE15	An earthquake’s intensity is commonly reported using the Mercalli Scale.	☐	☐

Appendix F: Raw Data Tables for the SILS Survey Results

Table F1

Summary of all results from the intervention group's pre-intervention SILS survey (N=52)

Subscale	Items	Response scores (N)				Mean (SD)
		4	3	2	1	
1. Individual interest in science	1a. Topics in physics	9.6% (5)	51.9% (27)	23.1% (12)	15.4% (8)	2.56 (0.87)
	1b. Topics in chemistry	21.2% (11)	48.1% (25)	21.2% (11)	9.6% (5)	2.81 (0.89)
	1c. The biology of plants	5.8% (3)	21.2% (11)	57.7% (30)	15.4% (8)	2.17 (0.76)
	1d. Human biology	25.0% (13)	32.7% (17)	30.8% (16)	11.5% (6)	2.71 (0.98)
	1e. Topics in astronomy	21.2% (11)	38.5% (20)	32.7% (17)	7.7% (4)	2.73 (0.89)
	1f. Topics in geology	3.8% (2)	40.4% (21)	46.2% (24)	9.6% (5)	2.38 (0.72)
	1g. Ways scientists design experiments	7.7% (4)	40.4% (21)	32.7% (17)	19.2% (10)	2.37 (0.89)
2. Enjoyment in Earth science	2a. I generally have fun when I am learning Earth science topics	9.6% (5)	61.5% (32)	26.9% (14)	1.9% (1)	2.79 (0.64)
	2b. I like reading about Earth science *	7.8% (4)	21.6% (11)	56.9% (29)	13.7% (7)	2.24 (0.79)
	2c. I am happy doing Earth science problems	3.8% (2)	53.8% (28)	38.5% (20)	3.8% (2)	2.90 (0.63)
	2d. I enjoy acquiring new knowledge in Earth science	15.4% (8)	59.6% (31)	25.0% (13)	0	2.90 (0.63)
	2e. I am interested in learning about Earth science	15.4% (8)	48.1% (25)	30.8% (16)	5.8% (3)	2.73 (0.79)
3. Triggered-SI	3a. My science teacher is exciting	21.2% (11)	69.2% (36)	7.7% (4)	1.9% (1)	3.10 (0.60)
	3b. When we do science, my teacher does things that grab my attention	15.4% (8)	59.6% (31)	21.2% (11)	3.8% (2)	2.87 (0.71)
	3c. My science class is often entertaining	13.5% (7)	61.5% (32)	23.1% (12)	1.9% (1)	2.87 (0.66)
	3d. My science class is so exciting it's easy to pay attention	7.7% (4)	34.6% (18)	53.8% (28)	3.8% (2)	2.46 (0.70)
4. Maintained-SI (feeling)	4a. What we are learning in science is fascinating to me	9.6% (5)	46.2% (24)	38.5% (20)	5.8% (3)	2.60 (0.75)
	4b. I am exited about what we are learning in science	7.7% (4)	36.5% (19)	50.0% (26)	5.8% (3)	2.46 (0.73)
	4c. I like what we are learning in science *	5.9% (3)	52.9% (27)	37.3% (19)	3.9% (2)	2.61 (0.67)
	4d. I find the science we do in class interesting	3.8% (2)	65.4% (34)	25.0% (13)	5.8% (3)	2.67 (0.65)
5. Maintained-SI (value)	5a. What we are studying in science is useful for me to know	17.3% (9)	44.2% (23)	32.7% (17)	5.8% (3)	2.73 (0.82)
	5b. The things that we are studying in science are important to me	3.8% (2)	32.7% (17)	51.9% (27)	11.5% (6)	2.29 (0.72)
	5c. What we are learning in science can be applied to real life	13.5% (7)	57.7% (30)	26.9% (14)	1.9% (1)	2.83 (0.68)
	5d. We are learning valuable things in science	13.5% (7)	61.5% (32)	21.2% (11)	3.8% (2)	2.85 (0.70)

Note. Items marked with an asterisk (*) have N=51. The mode for each item is shaded.

Table F2

Summary of all results from the intervention group's post-intervention SILS survey (N=52)

Subscale	Items	Response scores (N)				Mean (SD)
		4	3	2	1	
1. Individual interest in science	1a. Topics in physics	21.2% (11)	48.1% (25)	21.2% (11)	9.6% (5)	2.81 (0.89)
	1b. Topics in chemistry	25.0% (13)	48.1% (25)	23.1% (12)	3.8% (2)	2.94 (0.80)
	1c. The biology of plants	9.6% (5)	28.8% (15)	53.8% (28)	7.7% (4)	2.40 (0.77)
	1d. Human biology	38.5% (20)	21.2% (11)	32.7% (17)	7.7% (4)	2.90 (1.01)
	1e. Topics in astronomy	30.8% (16)	34.6% (18)	28.8% (15)	5.8% (3)	2.90 (0.91)
	1f. Topics in geology	21.2% (11)	42.3% (22)	34.6% (18)	1.9% (1)	2.83 (0.79)
	1g. Ways scientists design experiments	13.5% (7)	46.2% (24)	32.7% (17)	7.7% (4)	2.65 (0.81)
2. Enjoyment in Earth science	2a. I generally have fun when I am learning Earth science topics	17.3% (9)	65.4% (34)	17.3% (9)	0	3.00 (0.59)
	2b. I like reading about Earth science	7.7% (4)	51.9% (27)	40.4% (21)	0	2.50 (0.64)
	2c. I am happy doing Earth science problems	15.4% (8)	51.9% (27)	30.8% (16)	1.9% (1)	2.81 (0.72)
	2d. I enjoy acquiring new knowledge in Earth science	19.2% (10)	55.8% (29)	23.1% (12)	1.9% (1)	2.92 (0.71)
	2e. I am interested in learning about Earth science	21.2% (11)	48.1% (25)	28.8% (15)	1.9% (1)	2.88 (0.76)
3. Triggered-SI	3a. My science teacher is exciting	40.4% (21)	46.2% (24)	11.5% (6)	1.9% (1)	3.25 (0.74)
	3b. When we do science, my teacher does things that grab my attention	30.8% (16)	53.8% (28)	15.5% (8)	0	3.15 (0.67)
	3c. My science class is often entertaining	30.8% (16)	51.9% (27)	17.3% (9)	0	3.13 (0.69)
	3d. My science class is so exciting it's easy to pay attention	13.5% (7)	42.3% (22)	44.2% (23)	0	2.69 (0.70)
4. Maintained-SI (feeling)	4a. What we are learning in science is fascinating to me	17.3% (9)	53.8% (28)	28.8% (15)	0	2.88 (0.68)
	4b. I am exited about what we are learning in science	11.5% (6)	53.8% (28)	32.7% (17)	1.9% (1)	2.75 (0.68)
	4c. I like what we are learning in science	9.6% (5)	67.3% (35)	23.1% (12)	0	2.87 (0.56)
	4d. I find the science we do in class interesting	13.5% (7)	71.2% (37)	15.4% (8)	0	2.98 (0.54)
5. Maintained-SI (value)	5a. What we are studying in science is useful for me to know *	7.8% (5)	52.9% (27)	29.4% (15)	7.8% (4)	2.65 (0.77)
	5b. The things that we are studying in science are important to me *	0	45.1% (23)	49.0% (25)	5.9% (3)	2.39 (0.60)
	5c. What we are learning in science can be applied to real life *	17.6% (9)	62.7% (32)	13.7% (7)	5.9% (3)	2.92 (0.74)
	5d. We are learning valuable things in science *	25.5% (13)	47.1% (24)	25.5% (13)	2.0% (1)	2.96 (0.77)

Note. Items marked with an asterisk (*) have N=51. The mode for each item is shaded.

Table F3

Summary of all results from the comparison group's pre-intervention SILS survey (N=43)

Subscale	**Items**	**Response scores (N)**				**Mean (SD)**
		4	**3**	**2**	**1**	
1. Individual interest in science	1a. Topics in physics	18.6% (8)	25.6% (11)	37.2% (16)	18.6% (8)	2.44 (1.01)
	1b. Topics in chemistry	23.3% (10)	39.5% (17)	25.6% (11)	11.6% (5)	2.74 (0.95)
	1c. The biology of plants	4.7% (2)	25.6% (11)	41.9% (18)	27.9% (12)	2.07 (0.86)
	1d. Human biology	25.6% (11)	30.2% (13)	32.6% (14)	11.6% (5)	2.70 (0.99)
	1e. Topics in astronomy	23.3% (10)	34.9% (15)	27.9% (12)	14.0% (6)	2.67 (0.99)
	1f. Topics in geology	4.7% (2)	37.2% (16)	41.9% (18)	16.3% (7)	2.30 (0.80)
	1g. Ways scientists design experiments	18.6% (8)	27.9% (12)	30.2% (13)	23.3% (10)	2.42 (1.05)
2. Enjoyment in Earth science	2a. I generally have fun when I am learning Earth science topics	2.3% (1)	67.4% (29)	20.9% (9)	9.3% (4)	2.63 (0.69)
	2b. I like reading about Earth science	2.3% (1)	34.9% (15)	41.9% (18)	20.9% (9)	2.19 (0.79)
	2c. I am happy doing Earth science problems	4.7% (2)	48.8% (21)	25.6% (11)	20.9% (9)	2.37 (0.87)
	2d. I enjoy acquiring new knowledge in Earth science	14% (6)	55.8% (24)	20.9% (9)	9.3% (4)	2.74 (0.82)
	2e. I am interested in learning about Earth science	20.9% (9)	39.5% (17)	23.3% (10)	16.3% (7)	2.65 (1.00)
3. Triggered-SI	3a. My science teacher is exciting	16.3% (7)	60.5% (26)	16.3% (7)	7.0% (3)	2.86 (0.77)
	3b. When we do science, my teacher does things that grab my attention	16.3% (7)	58.1% (25)	23.3% (10)	2.3% (1)	2.88 (0.70)
	3c. My science class is often entertaining	11.6% (5)	67.4% (29)	18.6% (8)	2.3% (1)	2.88 (0.63)
	3d. My science class is so exciting it's easy to pay attention	11.6% (5)	27.9% (12)	55.8% (24)	4.7% (2)	2.47 (0.77)
4. Maintained-SI (feeling)	4a. What we are learning in science is fascinating to me	16.3% (7)	41.9% (18)	25.6% (11)	16.3% (7)	2.58 (0.96)
	4b. I am exited about what we are learning in science	11.6% (5)	44.2% (19)	32.6% (14)	11.6% (5)	2.56 (0.85)
	4c. I like what we are learning in science	18.6% (8)	34.9% (15)	25.6% (11)	20.9% (9)	2.51 (1.03)
	4d. I find the science we do in class interesting	20.9% (9)	44.2% (19)	27.9% (12)	7.0% (3)	2.79 (0.86)
5. Maintained-SI (value)	5a. What we are studying in science is useful for me to know	11.6% (5)	48.8% (21)	25.6% (11)	14.0% (6)	2.58 (0.88)
	5b. The things that we are studying in science are important to me	11.6% (5)	34.9% (15)	34.9% (15)	18.6% (8)	2.40 (0.93)
	5c. What we are learning in science can be applied to real life	14.0% (6)	48.8% (21)	27.9% (12)	9.3% (4)	2.67 (0.84)
	5d. We are learning valuable things in science	14.0% (6)	53.5% (23)	20.9% (9)	11.6% (5)	2.70 (0.86)

Note: The mode of each item is shaded.

Table F4
Summary of all results from the comparison group's post-intervention SILS survey (N=43)

Subscale	**Items**	**Response scores (N)**				**Mean (SD)**
		4	**3**	**2**	**1**	
1. Individual interest in science	1a. Topics in physics	14.0 (6)	27.9 (12)	30.2 (13)	27.9 (12)	2.28 (1.03)
	1b. Topics in chemistry	23.3 (10)	37.2 (16)	32.6 (14)	7.0 (3)	2.77 (0.90)
	1c. The biology of plants	7.0 (3)	27.9 (12)	39.5 (17)	25.6 (11)	2.16 (0.90)
	1d. Human biology	18.6 (8)	32.6 (14)	37.2 (16)	11.6 (5)	2.58 (0.93)
	1e. Topics in astronomy	27.9 (12)	32.6 (14)	20.9 (9)	18.6 (8)	2.70 (1.08)
	1f. Topics in geology	11.6 (5)	25.6 (11)	44.2 (19)	18.6 (8)	2.30 (0.91)
	1g. Ways scientists design experiments	9.3 (4)	27.9 (12)	37.2 (16)	25.6 (11)	2.21 (0.94)
2. Enjoyment in Earth science	2a. I generally have fun when I am learning Earth science topics	14.0% (6)	41.9% (18)	30.2% (13)	14.0% (6)	2.56 (0.91)
	2b. I like reading about Earth science	7.0% (3)	25.6% (11)	41.9% (18)	25.6% (11)	2.14 (0.89)
	2c. I am happy doing Earth science problems	11.6% (5)	25.6% (11)	39.5% (17)	23.3% (10)	2.26 (0.95)
	2d. I enjoy acquiring new knowledge in Earth science	11.6% (5)	51.2% (22)	18.6% (8)	18.6% (8)	2.56 (0.93)
	2e. I am interested in learning about Earth science	18.6% (8)	37.2% (16)	23.3% (10)	20.9% (9)	2.53 (1.03)
3. Triggered-SI	3a. My science teacher is exciting	14.0% (6)	65.1% (28)	7.0% (3)	14.0% (6)	2.79 (0.86)
	3b. When we do science, my teacher does things that grab my attention	18.6% (8)	51.2% (22)	20.9% (9)	9.3% (4)	2.79 (0.86)
	3c. My science class is often entertaining	20.9% (9)	39.5% (17)	32.6% (14)	7.0% (3)	2.74 (0.88)
	3d. My science class is so exciting it's easy to pay attention	9.3% (4)	23.3% (10)	41.9% (18)	25.6% (11)	2.16 (0.92)
4. Maintained-SI (feeling)	4a. What we are learning in science is fascinating to me	11.6% (5)	32.6% (14)	34.9% (15)	20.9% (9)	2.34 (0.95)
	4b. I am exited about what we are learning in science	14.0% (6)	23.3% (10)	44.2% (19)	18.6% (8)	2.33 (0.94)
	4c. I like what we are learning in science	18.6% (8)	30.2% (13)	34.9% (15)	16.3% (7)	2.51 (0.98)
	4d. I find the science we do in class interesting	16.3% (7)	32.6% (14)	34.9% (15)	16.3% (7)	2.49 (0.96)
5. Maintained-SI (value)	5a. What we are studying in science is useful for me to know	9.3% (4)	41.9% (18)	30.2% (13)	18.6% (8)	2.42 (0.91)
	5b. The things that we are studying in science are important to me	9.3% (4)	30.2% (13)	39.5% (17)	20.9% (9)	2.28 (0.91)
	5c. What we are learning in science can be applied to real life	11.6% (5)	46.5% (20)	27.9% (12)	14.0% (6)	2.56 (0.88)
	5d. We are learning valuable things in science	16.3% (7)	46.5% (20)	27.9% (12)	9.3% (4)	2.70 (0.86)

Note: The mode of each item is shaded.