Storyboard:
Primary school students designing
and making explanatory animations

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Abstract

This practitioner action research project involved eight students from an inner Melbourne Primary School who created explanatory animations in 2011. Third generation activity theory was used in this study as a methodological lens to examine the explanatory animation process at various stages as both a tool and an object. The explanatory animation creation task was initially the object of activity but as reflexive practice, the project itself became the unit of analysis. My claim here is that the children’s mental models, as depicted through the animation key frames, functioned as both flexible models and diagnostic tools.

Vygotsky and Sakharov’s dual stimulation method was used as a theoretical framework to conduct the current study due to the close unity between conceptual tasks and their resolution. The dual stimulation method requires that “the subject must be faced with a task that can only be resolved through the formation of concepts” (Vygotsky, 1987, p. 124). Vygotsky explained the nature of this link by stating that “the path through which the task is resolved in the experiment corresponds with the actual process of concept formation” (ibid, p. 128).

This research provides a chronology of the children's conceptual consolidation by providing a tangible insight into the children's evolving mental models.
Declaration

This is to certify that:

(i) the thesis comprises only my original work except where indicated,

(ii) due acknowledgement has been made in the text to all other material used,

(iii) the thesis is less than 100,000 words in length, exclusive of the reference list and appendices.
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Chapter 1. Introduction

Visual learning is not new. From the Paleolithic cave paintings, to the Egyptian hieroglyphics, to the visual language used in our modern-day world, we have always been a visual society (Gangwer, 2009, p. x).

Setting the scene: 8 children, 1 multifaceted task

This study is about the conceptual consolidation of eight primary school children in 2011 who were given the challenge of creating explanatory animations for their chosen topics. The title for this research project is Storyboard. When Walt Disney first used the term storyboard in the 1930s, he essentially invented a pre-production animation technique that guided the design process for cartoons. The use of storyboarding has recently expanded beyond entertainment contexts into educational research. Mitchell et al. (2011) have encouraged researchers to “incorporate the storyboard into the repertoires of visual data possibilities” (p. 219), as it is a semiotic framework for expression and meaning.

In the current study, the evolving representations of each child’s conceptual journey were deemed to be more important than the final animation artefacts. This assumption arose from an earlier study (Jacobs, 2007), where I had used explanatory animations as a teaching medium for a case study involving six of my primary school teaching colleagues. I made a series of explanatory animations and collected pre-test and post-test data from these six colleagues. An unexpected outcome of that study occurred retrospectively when I realised that the person who had learned the most from the explanatory animations was actually me as the author. My realisation that the explanatory animation creation process can directly impact the conceptual consolidation of the animation author provided a clue that these two issues could be researched concurrently. This was a significant finding for me as it eventually provided a rationale to commence the current study working with eight children over a five-month period through seventeen weekly one-hour animation sessions.

The storyboards that the eight child participants worked on eventually became source material for their completed animations. Unlike a traditional storyboard where the images and words are used to plan the actual imagery, these eight children were able to use the “Save as.PNG” function within Microsoft PowerPoint, where each PowerPoint slide of their storyboard became the ‘frames’ for this animation imagery. Consequently, I was able to see what the children were thinking through their evolving
representations. This was very exciting for me as both a teacher and a researcher as the children’s ideas were literally taking shape on their computer screens. As the children were also writing voice-over scripts for their narration, their requests for assistance allowed me to quickly ascertain where they were heading through their explanatory draft material. These interactions seemed to resonate with what Vygotsky (1962) described as “tapping the child’s thinking” (p. 52). It is this insight into the student’s thinking which constitutes the theoretical interest in the current study. As Waldrip and Prain (2013) have noted:

Teachers should view representational work by students, including verbal accounts of the topic, as a valuable window into students’ thinking and evidence of learning. This assessment can be diagnostic, formative or summative (p. 27).

The flexibility of the digital environment, where representational ideas could be tried and literally undone with the click of a mouse, caused me to think in terms of the children playing and tinkering with models. Clement (2008) has identified a gap at the core of conceptual change theory as “we do not have an adequate cognitive model of the basic cognitive change process; we do not have a good understanding of how flexible models are constructed” (p. 417). This is an important issue because the notion of a model being flexible is consistent with the constructionist view of learning where meaning is constructed, and also deconstructed, by the learner. The current study seeks to investigate how meaning can be constructed and socially negotiated, through the various combinations of words, metaphors and representations to forge important links between animation pedagogy and the conceptual change literature.

Statement of the research question

This study asks:

In what ways can storyboarding and explanatory animation creation enable primary school students to articulate and consolidate their conceptual understanding?

The arrows in Figure 1.1 are to show that these two elements are mutually informative:
The mutually informative nature of these two processes is not a claim from the current study. Rather, it is an introductory premise based on my own experience that explanatory animation creation and conceptual consolidation are iterative processes. Vygotsky (1987) stated that his most important insight into the process of conceptual consolidation was that a concept “develops” (p. 170) in the mind of the learner. This implies that conceptual growth must be studied over time.

Goldman (2008) also noted “there is an important difference between learners generating representations once they have understood the content and learners generating representations that help them in the process of understanding” (p. 367 original emphasis). This difference is exemplified in activities where students have the opportunity to make multiple representations, preferably over long periods of time.

**Thesis overview**

Chapter 2 reviews some of the literature associated with conceptual change. There is very little in the literature about the impact of the explanatory animation creation process on the animation author’s conceptual understanding. This is because the vast majority of the educational animation literature is focused on the viewers of explanatory animations rather than the makers. Hubscher-Younger and Narayanan identified this gap in 2008 which is the same year that I commenced the current study:

Extant literature contains many studies of the efficacy of animations and other kinds of representation created by expert teachers and researchers. However, studies on the characteristics and efficacy of student-created representations are much less numerous (p. 237).
The “student-created representations” to which Hubscher-Younger and Narayanan refer, were created by undergraduate students rather than primary school students. The available literature is even smaller when the focus shifts to child authors rather than adult authors. In spite of this scarcity, or even because of it, there are other relevant issues pertaining to the explanatory animation creation task that have not been deeply explored, such as transmediation across multimodal constructs, using words and graphics during the animation creation process.

As explanatory animation creation is a multifaceted task, some methodological content is included in the literature review by way of an introduction to Cultural Historical Activity Theory (CHAT) as an “umbrella methodology” (Anning, Cullen & Fleer, 2009, p. 1) that has evolved from Vygotsky and Sakharov’s dual stimulation method. These are complementary methodologies as CHAT has evolved from Vygotsky and Sakharov’s original method of dual stimulation, which was the “cornerstone” (Giest, 2008, p. 103) of the CHAT school.

The dual stimulation method is based on the premise that the second stimulus will provide agency for the child who is engaged in a problem solving activity occasioned by the first stimulus. For Vygotsky, the focus was always on the mediating role of the second stimulus after the first stimulus had established the context. In the current study, the first stimulus for each child was the task of explaining the topic that he or she had chosen. The second stimulus provided the means for achieving this through the process of creating an explanatory animation. Vygotsky alluded to the conceptual affordances of the mediating device (as a second stimulus) by suggesting that the “subject must be faced with a task that can only be resolved through the formation of concepts” (Vygotsky, 1987, p. 124). Vygotsky explained the nature of this resolution by stating that “the path through which the task is resolved in the experiment corresponds with the actual process of concept formation” (ibid, p. 128). Hence, the power of explanatory animation creation process is its ability to track and illustrate the conceptual-developmental pathway.

The notion of activity is particularly important for this study because each of the child participants was required to perform a variety of technical and pedagogical roles, as their explanatory animation creation task was clearly multifaceted. Harel and Papert (1991) were amongst the earliest researchers to note that constructing digital artefacts is a multifaceted task:
The child-producer who wants to design a lesson on the computer must learn about the content, become a tutor, a lesson designer, a pedagogical decision maker, an evaluator, a graphic artist, and so on (p. 78).

Throughout this study, activity is seen in terms of Vygotsky’s Zone of Proximal Development (ZPD) where I provided assistance to the children as a more capable or experienced helper. As I was also the researcher, the ZPD afforded me the opportunity to share a close proximity with the children, which further enabled me to document their conceptual journeys according to the qualitative perspective and practices of naturalistic inquiry.

Chapter 3 defines the methodology for this research as an explanatory case study conducted as practitioner action research. The research methodology chapter then outlines twelve sources of data that were generated throughout the study and provides an analytical framework for how these data will be analysed. Vygotsky’s ZPD forms the basis for these analyses as ongoing comparisons between what each child knew about their chosen topic and what I knew. In each case, my own understanding of the content knowledge for each of the children’s animations was also expanded.

Chapter 4 provides an analysis of the twelve data sources in the form of eight portraits where each of the children’s conceptual journeys is presented as a narrative with accompanying screen shots from their animations. Combining and critiquing relevant events from these multimodal data sources chronicled the key instances of conceptual change for each child and also for me. Each child’s explanatory animation creation task was conducted using computers and so all of the resultant data sources were digital. As such, it is not uncommon for a thesis that generates digital artefacts to have an accompanying data disc containing such media (Appendix A). These data can also be viewed online at www.brendanpauljacobs.com.

Chapter 4 concludes with three montages from the eight portraits which, in turn, discuss the Vygotsky’s ZPD with reference to the zone itself, the proximity afforded to me as a researcher throughout this project and the conceptual development that each child experienced.

Chapter 5 presents further discussion around activity. The CHAT triangle is used as a prism metaphor to help understand some of the complexities involved in the division of labour between the children and myself. Animation design guidelines are also examined using the same prism metaphor in relation to rules. Further discussion is
also made about the animation medium where I present a new definition of animation as \textit{variant graphics}.

Chapter 6 concludes this thesis with my presentation of three complementary theories of conceptual consolidation, based on the actual experiences and progress of the eight children who participated in the current study. The three theories cover a definition of what a concept is, an articulation of some of the main phases of conceptual consolidation, and a suggestion of what might constitute evidence of conceptual consolidation drawing on Bruner’s (1966) notion that the ability of children to paraphrase is a hallmark of comprehension.

Chapter 6 also addresses the research question in terms of the explanatory animation artefacts and the processes that are used to create them. The explanatory animations artefacts are shown to be flexible models at every stage of the construction process. Accordingly, the explanatory animation creation task is shown to have functioned as a transmediating tool for cross-modal cognition. The explanatory animation creation task provided a very specific window into the ubiquitous phenomenon of conceptual change. It is the hope of the current study that this window might be opened wider.

**Limitations of this study**

The current study is the work of a single researcher, working in a single school. I was the only researcher directly involved in this project but there was a rationale for conducting this study in its current form. If the aim was simply for each child to consolidate their knowledge of a topic, then it would not matter if others assisted. A third party (researcher) could have been involved in helping each child with their conceptual consolidation, but it would have been harder for me to articulate when and \textit{where} these changes occurred if a third party was involved. Both metaphorically and literally, I had to go along for these conceptual rides if I was going to be able to articulate each journey with sufficient insight to justify any claims I might eventually make.\textsuperscript{1}

Another limitation concerned the choice of technology as I mandated that all of the case study participants would use PowerPoint to generate and organise their animation imagery. In one sense, this was a limitation, but it was also helpful that all of the participants were already familiar with the basic functionality of this software when

\footnotesize\textsuperscript{1} My two university supervisors confirmed my findings but never had the opportunity to meet the children.
commencing this project. Gargarian (1996) has observed a paradox relating to design restraints by claiming there is “freedom in restrictions” (p. 132). The paradox is that boundaries define the parameters, which then helps to guide the progresses. These same design parameters then became a catalyst for creativity.
Chapter 2. Literature review

Through the window we could see eight children, each working on their own computer. They were spread out across the room as they were all working on individual projects having chosen different topics for their explanatory animations. The teacher was also the researcher but he behaved more like a teacher, partly because he actually was their teacher each week for Performing Arts sessions and he’d known the children for many years. His interactions with the children involved discussions and a critique of the imagery and words that they were using to explain topics for which they claimed no prior expertise. Towards the end of the session, each child began recording their own voice as a reflection about their progress and plans.

Introduction to the literature review

The empirical field for the Storyboard project is primary school animation authoring. Surprisingly, in a technologically rich era where electronic screens are a permanent part of our educational landscape, this field is fertile but dormant. The current study sought to investigate what impact the explanatory animation creation task has on the conceptual understanding of the animation author. A survey of the literature about explanatory animation creation would suggest that this multifaceted task is the exclusive domain of professional animators. This assumption runs so deep throughout the literature that it is not even questioned but, rather, accepted as a given. With the possible exception of Hoban, Nielsen and Carceller (2010) whose research investigated pre-service teachers using Claymation, it appears that there is no literature about children making explanatory animations for the sake of their own learning. For this reason, the explanatory animation task, although crucial to the current study, is largely absent from the literature review. This important theme will be revisited in Chapter 5 as a discussion informed by the data analysis and results from the current study.

As the overarching reason for the explanatory animation task in the current study was learning, this literature review begins by looking at constructionism to harness Papert’s (1991, 1993) idea that producing the right kind of knowledge artefacts can be both engaging and generative for learning and knowledge creation. Conceptual change is then explored as a re-evaluation of what concepts are and how they might inform learning. Visualisation and mental models then steer this literature review towards
issues pertaining to representation whilst retaining the overarching interest in teaching and learning.

The explanatory potential of representations is then developed through other multimodal contexts such as storyboards and models. This focus on representation includes a discussion on the use of metaphors and analogies as mediating devices. The ability to use metaphors for an explanatory purpose is an example of paraphrasing through the identification and articulation of relevant variables. The importance of this process leads the discussion into a re-evaluation of the abstract and the concrete as the construction of an explanation using metaphors surfaces the designer’s conceptual understanding of their subject matter through their ability to make and justify these connections. Such design choices are further examined as design principles for teaching with animation after an introduction to learning from viewing explanatory animations.

A discussion on concept formation and the dual stimulation method leads into a critique of CHAT and its value to this study to forge strong theoretical links between the conceptual side of this project and the methodology that was devised to implement it.

Vygotsky’s zone of proximal development (ZPD) then brings the dynamics of teaching and learning into focus as “mutual zones” (John-Steiner, 2000, p. 177) of proximal development for the co-construction of meaning as collaborative partners. The ZPD constitutes a major theme for this study that is developed throughout the rest of the thesis.

The final discussion in this literature review involves schematic diagrams as conceptual metaphors as schematic diagrams and explanatory animations share many of the same design constraints in the interests of communicative clarity. The creation of schematic diagrams places deliberate limits on the graphic imagery involved as, by definition, schematic diagrams are selective rather than exhaustive. Likewise, careful consideration must also be given to decisions regarding essential content information for the purpose of effective communication. Schematic diagrams and constructionism as presented as metaphorical bookends for this literature review to suggest that the creation of explanatory artefacts can be generative for learning.
Constructionism

The learning theory that permeates the current study is constructionism as articulated by Harel and Papert in the seminal book *Constructionism* (1991). The current study sought to investigate connections between the act of making an explanatory animation and the process of conceptual consolidation. Constructionism provides a useful framework to investigate such dynamics due to the central focus on building artefacts and how these, in turn, become mediating tools for learning. Accordingly, from the constructionist point of view, “knowledge is a modelling process, which shapes and edits reality to make it intelligible” (Floridi, 2011, p. 301).

Papert (1991) acknowledged that his formulation of constructionism was built on the foundation laid by Piaget's constructivism. Edith Ackermann (1991) was well qualified to comment on both of these epistemologies having worked closely with both Piaget and Papert for many years:

> Because of its [constructionism’s] greater focus on learning through making rather than overall cognitive potentials, Papert’s approach helps us understand how ideas get formed and transformed when expressed through different media, when actualized in particular contexts, when worked out by individual minds (p. 4 original emphasis).

The production of digital artefacts generates multiple sources of data. Reconciling these multimodal sources of data became a research interest for Kafai and Resnick (1996) who theorised that the ideals of constructionism can integrate both design theories and learning theories which have traditionally been seen as emphasising either the product (design) or the process (learning). They note that “both design theorists and learning theorists now view ‘construction of meaning’ as a core process” (Kafai & Resnick, 1996, p. 4). According to Bateman (2008) this cross-pollination of design and learning has paved the way for digital representations and artefacts to become part of the qualitative researcher’s tool kit in instances where conceptual artefacts are constructed. Bereiter (2002) has reconciled even deeper epistemological issues inherent in design and learning by suggesting that improvement is a more fruitful attribute than truth:

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1 Interestingly, as I’m finishing this section in August 2014, the 2014 Constructionism conference is being held in Vienna. According to the program, many of the sessions are about the use of model-based reasoning as conceptual models. This theme is developed later in this literature review under “Explanatory models”.

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You cannot know or justify claim that you are getting closer to truth. That would require that you already have an idea of what the truth is. But you can specify ways in which one conceptual artifact is an improvement over its predecessor. You can show how it overcomes faults that were detected in the predecessor, how it accounts for facts that an older theory could not, or merely that it does the same conceptual job more economically or elegantly (p. 429).

Bereiter’s quest for improvement is fundamental to the current study as the children’s explanatory animation creation process demonstrated instances of incremental improvement and showed how these iterations might display the learning that was embedded in the children’s conceptual artefacts. For Papert (1993), working with artefacts also means that learning can take place outside of the learner’s head as an artefact can be “shown, discussed, examined, probed, and admired. It is out there” (p. 142).

Rusk, Resnick and Cooke (2009) described constructionism as “a different model of learning and education, where the focus is on construction rather than instruction” (p. 19, original emphasis). This distinction between construction and instruction was occasioned by Papert’s (1980) famous speech to Japanese educators when he equated teaching with instruction and learning with construction saying “teaching is important, but learning is much more important” (original emphasis). Papert’s dismissal of instructionism (i.e., the idea that improved learning comes from improved instruction) formed the basis of his assertion that attempts to improve instruction alone are misdirected.

Papert and Harel (1991) further explained the contrast between constructionism and instructionism as an epistemological issue that goes “beyond the acquisition of knowledge to touch on the nature of knowledge and the nature of knowing” (p. 8). Papert (1993) continued to draw this distinction between teaching and learning by stating that the goal of constructionism is to “teach in such a way as to produce the most learning for the least of teaching” (p. 139). For Sutter (2001), the challenge is for constructionists to explain how instruction fits in with constructionist learning principles. Hoban, Nielsen and Carceller (2010) described constructionism as a “meta-theory” (p.434) rather than an explicit learning theory. They also noted that there are very few studies using constructionism as a theoretical framework to “articulate the process of designing and making artefacts and justify why this process is beneficial for student learning” (ibid, p. 435). It is Floridi (2011) who has articulated and expanded constructionist principles through his article A defence of constructionism: Philosophy
as conceptual engineering. The six principles that Floridi presented are paraphrased in the following list:

1. The principle of knowledge - Only what is constructible can be known. (Anything that cannot be constructed, at least conceptually, can only be subject to working hypotheses).
2. The principle of constructability - Working hypotheses can be investigated through conceptual models and simulations.
3. The principle of controllability - Models must be controllable.
4. The principle of confirmation - Confirmation or refutation relates to the model itself rather than the system being modelled.
5. The principle of economy - The fewer resources used in a conceptual model the better.
6. The principle of context-dependency - Points of correspondence between simulation and simulated are local rather than global (pp. 300-301).

These six principles are applicable to the current study as the primary school children used the conceptual modelling process to enhance and expand their understanding. As Nersessian (2008) has noted, modelling has a “generative” quality (p. 48). Hence, the next section focuses on conceptual change and how this is a generative process that leads towards conceptual consolidation.

**Conceptual change and conceptual consolidation**

A key component of the research question for the current study is conceptual change. Conceptual change is still the most commonly used term to describe the learning of concepts, which according to Chi (2008), is primarily a process of classification. Hewson (1992) discussed how the word “change” has a wide semantic range (pp. 3-7) in relation to conceptual learning, although the assumption within the conceptual change literature is that the change is leading to improvement. Smith, diSessa and Roschelle (1993) used the word “refinement” (p. 150) as a more nuanced term. I have used the term conceptual consolidation (Oliver & Ebers, 1998; Ortiz & Wright, 2010) throughout the current study, as the purpose of this research is to investigate how the explanatory animation creation process might effect conceptual change up to a point that demonstrates consolidation.
The more problematic word in the heading of this section is actually concept, as there is no consensus as to what a concept actually is. Adherence to a classification model of concepts led Jackendoff (1999) to make a distinction between internal and external concepts using the terminology of “I” and “E” concepts (p. 306) based on Chomsky’s (1986) notion of internal and external language. This I-E distinction might be generative for hierarchies and taxonomies of concepts but it is not conducive to defining what a concept is. Laurence and Margolis (1999) discussed a range of conceptual definitions before concluding that, “for most concepts, there simply aren’t any definitions” (p. 14). Medin and Rips (2005) introduced their summary of the cognitive science literature on conceptual change by saying that the word concept itself is “up for grabs” (p. 37). Perhaps the problem of defining a concept is inherent in language itself. As Evans (2006) argued, words don’t have meaning per se, and so their meaning must be inferred as a “function of situated use” (p. 527). In this sense, a concept can be defined according to how it is used. In the current study, the word concept is used as an explanatory concept (Murphy, 2000; Thomas, 1977; Zif, 1983), which is then defined as anything that requires explanation.

There are also different perspectives in the literature about the nature of conceptual change but one common thread is that conceptual change is seen as a phenomenon that occurs throughout a person’s life and is therefore developmental. Hence, a central issue within the conceptual change literature concerns the nature and rate of change. Opinion is divided as to whether conceptual change is drastic or incremental. In the context of scientific thought, Kuhn (1970) characterised conceptual change as revolutionary, exhibiting paradigm shifts. However, Toulmin (1972) rejected this view, citing examples of a more gradual, evolutionary nature, such as Darwin’s understanding of biology exhibiting a consistent application of perpetual variation. Perhaps what is most illustrative from this debate is that there is ample support for each view.

What is common to both conceptual change and conceptual consolidation, however, is that they both speak of concept formation. “The main question about the process of concept formation - or about any goal-directed activity - is the question of the means by which the operation is accomplished” (Vygotsky, 1962, pp. 55-56). This issue of means continues to be of interest to science education, and particularly model-based reasoning (Nersessian, 1984, 2002, 2008, 2012) which speaks of an “interplay between concept formation and modelling practices” (2012, p. 222).
Özdemir and Clark (2007) compiled an overview of conceptual change theories where they organised the literature into two groups according to epistemological differences, namely:

- Knowledge as elements (i.e., individual pieces of information, often facts or findings)
- Knowledge as theory (i.e., systems of thought based on connections and relationships)

Many researchers affirm the knowledge as elements perspective (Clark, 2006; diSessa, Gillespie & Esterly, 2004; Harrison, Grayson & Treagust, 1999). The knowledge as theory group is also strongly represented in the literature (Ioannides & Vosniadou, 2002; Wellman & Gelman, 1992). Wiser and Amin (2001) suggested that the answer might be somewhere in the middle because there is obvious merit, and evidence, for each view. The process of conceptual change varies in different contexts depending on the age of the person and the intrinsic complexity of each concept. Carey (1999) is insightful here by suggesting that conceptual restructuring is not global, but domain specific.

It is worth noting that the intended contrast in Özdemir and Clark's schema is between knowledge as elements and knowledge as theory, where knowledge is the common link, rather than understanding. The semantic range of common words such as knowledge, understanding and information have much overlap. The Oxford English Dictionary defines “knowledge” in various ways such as a general “fact” through to “familiarity gained by experience” and even a “person's range of information”. Knowledge as information might explain why the practice of classification is so widespread in the conceptual change literature. By contrast, Vygotsky's insight about concepts developing (Vygotsky, 1987) is more in line with understanding as conceptual consolidation is clearly a dynamic process where ‘the concept does not emerge in a static and isolated form but in the vital process of thinking and resolving a task” (p. 128).

There is a long tradition within the conceptual change literature to see conceptual change as a replacement of misconceptions with more accurate conceptions. Smith, diSessa and Roschelle (1993) have called for a more nuanced approach to balance this view:
The goal of instruction should be not to exchange misconceptions for expert concepts but to provide the experiential basis for complex and gradual processes of conceptual change. Cognitive conflict is a state that leads not to the choice of an expert concept over an existing novice conception but to a more complex pattern of system-level changes that collectively engage many related knowledge elements (p. 154).

Terms such as “conceptual conflict” (ibid) and “conceptual exchange” (Hewson, 1992, p. 4) revisit the issue of whether concepts are replaced or modified. This is another way of looking at the rate of change issue from the 1970s. Of interest is the more recent interest in the illusion of explanatory depth (IOED) (Rozenblit & Keil, 2002). Keil (2006) defined the IOED by stating that:

People of all ages tend to be miscalibrated with respect to their explanatory understandings; that is, they think they understand in far more detail than they really do how some aspect of the world works or why some pattern in the world exists (p. 242).

The IOED could then be paraphrased as a phenomenon whereby people often settle for an understanding of what rather than how. Keil (2006) suggested that one reason for the IOED is that identifying causation is often equated with understanding. For example, a person might realise that kidneys clean blood but not know how. Keil (2006) attributes the IOED to an initial surge of insight:

When we learn one of these causal-functional relations, we get an appropriate surge of insight into an explanatory relation that we did not have before. The problem occurs when we attach that surge of insight to an inappropriately low level of analysis (pp. 242-243).

Alter, Oppenheimer and Zemla (2010) are insightful here by noting that this overconfidence is most noticeable in oral language and that it peaks “before attempting to express those explanations in writing” (p. 10). It would then appear that the task of writing conceptual explanations has a generative effect on a person when they are challenged to find the right words for their explanation.

The knowledge as elements versus knowledge as theory issue might suggest a continuum between these two positions, but it also follows that both elements and theory are involved in all cases as a theory can’t exist without elements and, likewise, a system can’t exist without components. The commonality between concepts and systems is worth exploring, as they both appear to have components and connections between these components. This is highly relevant to the current study because the children’s explanatory animation creation task involved constructing imagery in addition
to speaking and writing to enhance their explanation of how these component parts might function, together.

**Concepts as systems and variables**

The Oxford English Dictionary defines a *system* as a "Complex whole, set of connected things or parts, organised body of material or immaterial things." In the most basic sense, a system implies relationships between component parts. The current study uses the term *variables* (Zimmerman, 2007) for the components parts of a system. A basic outline of scientific terminology is provided in Table 2.1 to define my use of the term ‘variable’ using two examples of how the following four variables impact one another during scientific experiments:

1. Independent variables
2. Dependent variables
3. Constant (control) variables
4. Extraneous variables

**Table 2.1**

*Examples and types of variables*

<table>
<thead>
<tr>
<th>Type of variable</th>
<th>Definition</th>
<th>Scientific experiment example using paper plane designs (Helmenstine, 2014)</th>
<th>Scientific experiment example contrasting two growing plants</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Independent variable</strong></td>
<td>The variable that is changed in an experiment</td>
<td>Design of the plane – length of wings</td>
<td>Water for one plant</td>
</tr>
<tr>
<td><strong>Dependent variable</strong></td>
<td>The variable that is measured</td>
<td>Flight of the plane – duration or distance of flight</td>
<td>Growth rate of the plant receiving water</td>
</tr>
<tr>
<td><strong>Control variable</strong></td>
<td>A variable that is kept the same during the experiment</td>
<td>Size of the paper</td>
<td>Sunlight for both plants</td>
</tr>
<tr>
<td><strong>Extraneous variable</strong></td>
<td>A variable that has no effect on an experiment</td>
<td>Colour of the paper</td>
<td>Colour of the pots</td>
</tr>
</tbody>
</table>
Of note from Table 2.1 is that variables need to be identified and articulated before they can be classified according to their interrelationships. Davydov (1990) used the relationships between variables within a conceptual system as a way to explain concepts in other domains such as economics. The complexities of economics, for instance, become more manageable when broken down into variables with corresponding relationships.

Similarly, variables within music can be understood according to their role in the musical system. One musical element, for instance, is melody. A melody can only be expressed through individual notes and yet an individual note only has melodic value in relation to other notes. This point was made by Christian von Ehrenfels when he published his essay entitled *On Gestalt Qualities* in 1890 and said that a transposed melody can be recognised even if it does not contain any of the same notes as the original. Musical transposition is a good example of a holistic structure because it affirms the relationships between variables using a system perspective. This musical example also influenced Langer's (1957) seminal work *Philosophy in a New Key* where meanings are “understood only through the meaning of the whole, through their relations within the total structure (p. 97).

Kuhn and Dean (2005) found that they could improve learning for children by explicitly reminding them to focus on one variable at a time. Kuhn and Dean’s method not only simplified the task for their students, but also implied the strategy of articulating what the focus actually was at any given time. Zimmerman (2007) also noted that scientific learning is “multifaceted” (p. 213), and that the isolation of variables is an important part of the scientific method. Kuhn, Iordanou, Pease and Wirkala (2008) have sought to expand this traditional view by asking “what else, beyond control of variables, is involved in the development of skilled scientific thinking?” (p.436). They suggested that skill in experimentation, skill in argumentation and an epistemological understanding of the nature of science will help induce scientific reasoning processes in children. It is this second area (i.e., skill in argumentation), that most informed the current study as the eight children were given the task of explaining their topics without actually participating in scientific experimentation per se. Instead, their task was largely representational and so the theoretical interest here shifts to visualisation and the existence of mental models.
Visualisation and mental models

An area of interest to the same cognitive psychologists who investigate conceptual change is the existence of mental models. According to Rapp (2007):

Mental models are internal representations of information and experiences from the outside world. Indeed, mental models have been discussed beyond psychology proper; they are often invoked by science educators to describe the types of representations that equate with adequate comprehension of educational material (p. 44).

Mental models depict an individual’s understanding of particular concepts. They are "representations that rely on a person's understanding, but are not always valid or reliable" (ibid, p. 45). For Rapp, the reliability of a mental model relates to its alignment with the topic. Hence, faulty models are common across various subject areas, ages and demographics for a variety of reasons ranging from the quality and nature of instruction through to other pedagogical considerations such as a student's prior knowledge (Carey, 1985; Diakidoy & Kendeou, 2001; Osbourne & Freyberg, 1985).

A challenge for teachers and researchers is trying to understand what students’ mental models actually look like. Explanations require students to construct mental models of the content from which they are presented, regardless of whether the explanation includes any diagrams. This is the essence of the ubiquitous phenomenon of visualisation. Gilbert (2007) argued that, “visualization is central to learning, especially in the sciences, for students have to learn to navigate within and between the modes of representation” (p. 9). Hence, visualisation is strongly associated with the development of mental models as mental models “refer to the model of the system actually constructed by the learner” (Mayer, 1993, p. 568). The structure of mental models gives representational form to the given or implied particulars of a concept but a mental model does not necessarily have a physical structure (Caws, 1974). The relevance of this duality for the current study is that the explanatory animation process facilitates tangible expressions of internal, mental models. Gilbert (2007) calls this an expressed model:

By its very nature, a mental model is inaccessible to others. However, in order to facilitate communication, a version of that model must be placed in the public domain and can therefore be called an expressed model (p. 12, original emphasis).

An expressed model is particularly useful to facilitate learning because it is tangible and thus available for further critique and discussion. Veresov (2013) described this as a basic premise pertaining to multimodality and knowledge representation, when he
suggested that representations must be visible before they can be observable, and they must be observable before they can be analysable.

**Multimodality and knowledge representation**

A *mode* is a specific type of communication such as language, imagery or gesture. Kress (2010) has expanded the definition of ‘mode’ to include attributes, such as colour. The commonality amongst modes is that they can convey meaning. Wright (2010) has articulated many of the modes including “gesture, body language, facial expressions, eye contact, dress, writing, speech, narratives, the mass media, advertising, drawing, photography, space, cuisine and rituals” (pp. 11-12) but was careful to note that for children, meaning is constituted by its total effect as *semiotic units* and should be “understood as a single multimodal act” (ibid, p. 14).

The format in which a mode might be expressed, such as paper, email or text message, is referred to as the *medium*. The animation medium is a composite mode containing elements such as imagery, language, colour, movement and music. Eisner (1982), Green (1988), Knobel and Lankshear (2007) and Wright (2010) have noted that each modality, “affords a particular type of meaning” (Harste, 2010, p. 29).

A fundamental presupposition that binds all systems of representation is that they have “the power to evoke something else” (Pratt & Garton, 1993, p. 1). Davis, Shrobe and Szolovits (1993) have taken this notion further by describing representations as a “surrogate” (p. 17) for that which they represent. Pratt and Garton (1993, pp. 1-9) provided some general principles of how representations evoke mental associations with objects:

1. **Internal** (i.e., mental imagery) and **external representations** (e.g., pictures, language) have some obvious overlap. For instance, “we cannot think about pictures, if we cannot represent them mentally” (Pratt & Garton, 1993, p. 2). Similarly, we cannot organise mental constructs without either imagery or language.

2. **The system of representation is distinct from the application of that system.** An example of this is how language is a system with an entire body of linguistic research and literature but the application of language is communication. Art is also a system with a body of artefacts (e.g., paintings,
sculptures, installations) but the application of art is creating and communicating thoughts and feelings through images and objects.

3. **The degree or extent to which representations are related to their objects**

   The degree or extent to which representations are related to their objects can be understood as “dimension[s] of arbitrariness” (Pratt & Garton, 1993, p. 3). At the most arbitrary side of this scale is language itself. For example, the symbol ‘5’ could have been attached to any number initially but in Roman numerals, the use of a ‘V’ symbol to represent the number 5 is less arbitrary because the V was chosen because it looks like an outstretched human hand with 5 fingers. Photographs and videos are considered to be the least arbitrary because they generally look realistic unless they are heavily stylised.

Whether internal or external, arbitrary or realistic, the representational focus of the current study is in the communicative intent of the person making a representation. Kress and van Leeuwen (2006) have noted how the person who makes a representation (i.e., sign-maker) displays their communicative interest through the “criterial aspects” (p. 7) evident in a depiction. Representations are then value laden according to these criterial interests. “Representation is never neutral: that which is represented in the sign, or in sign-complexes, realizes the interests, the perspectives, the positions and values of those who make signs” (Kress & Mavers, 2005, p. 173). Jewitt (2008) has also noted that *mode and meaning* are deliberately aligned when constructing multimodal texts:

> How knowledge is represented, as well as the mode and media chosen, is a crucial aspect of knowledge construction, making the form of representation integral to meaning and learning more generally (p. 241).

Mode and meaning has its origins in the notion of *form and function*. Form and function are often discussed together as important design issues. Indeed, the reciprocal relationship between form and function has been discussed for centuries. Sullivan (1896) coined the phrase “form ever follows function” (p. 407) but attributed the idea to the Roman architect Marcus Vitruvius Pollio. According to Andreou (2013), “in every attempt to communicate information the concepts of the medium and the message, form and content takes precedence” (p. 12). The point is that the analysis of the form should begin with an analysis of the function.

Analysing the function of a representation is an iterative process. Bateman (2008) suggested that a key to understanding multimodality is to understand the genre to which it belongs. He prefers the term “multimodal documents” (p. 9) for static pictures due to the way that additional elements such as arrows and notations can enhance
meaning. Wright (2011) has further noted how the function of drawing for young children can extend beyond aesthetics and communication to include both provisional and generative elements. In this way drawing can surface what they "already know, what they are grappling with and what they are motivated to explore further" (pp. 171-172). Engeström and Middleton (1996) also noted these reflexive affordances by stating that, "visual representations serve a reflexive function in that they break down the tight flow of written argument, forcing both the writer and the reader to stop and look, and then to realign the two modalities" (p. 5). It would appear that realigning the two modalities of graphics and language is intrinsic to the process of storyboarding.

The affordances of storyboards

A storyboard, in its most basic form, is a linear presentation of ideas using pictures and (usually) words. Using pictures and art to represent scenarios is an ancient practice with countless examples throughout history. The storyboard is a continuance of this tradition but it serves the unique and specific purpose of scripting movement for animations and films. According to Canemaker (1999), "storyboarding was invented at the Disney Studios and is today a worldwide standard procedure for the production of both animation and live-action films and video" (p. ix).

The storyboarding technique is still as central and useful as it was back in the 1930s but the process has now been enhanced through the use of computers. Computer-aided storyboarding facilitates the rendering of the storyboard frames into draft animations called animatics. The purpose of both traditional storyboards and animatics is to improve efficiency by avoiding the time and expense of creating imagery which won't be used. In this sense, storyboards assist and effectively troubleshoot the storytelling process as useful planning tools.

As the children in the current study were using storyboarding as a tool to create their animations, the various stages of the storyboarding process were also informed by using some of the same techniques employed by filmmakers more generally. As with film production, there are three main stages of the video production process namely pre-production, production and post-production (Steiff, 2005). Planning is normally done at the pre-production stage. The purpose and inherent utility of planning the order of the various scenes is to make the process of filming more efficient because the production proceeds in accordance with the storyboard plan. In this sense storyboards afford “an intermediate stage between the script and the editing process; it
could, in fact, be seen as a form of pre-editing” (Michelson, 1993, p. 8).

An important new perspective about the affordances of storyboards was found by Mitchell, de Lange and Moletsane (2011) through their work with women in Rwanda to make short documentaries about gender inequality. They found that the group discussions surrounding the creation of storyboards were so fruitful (and time consuming), that they didn’t end up continuing with the filming stage. In this instance, where a final film was never made, “the storyboard became the product” (ibid, p. 224) which led them to conclude that most of the learning occurs during the storyboarding process, regardless of whether the storyboard is actually used to generate a final video artefact.

The affordances of storyboards would then appear to be more than a sum of its component parts (i.e., written text, imagery, movement, narrative, colour and so on) because the storyboard has its own affordance of order. This forces a designer to “break down a concept into its constituent parts and place them in a sequence” (Hoban, Nielsen & Carceller, 2010, p. 439). A storyboard not only implies order, it also implies rearranging order. The affordance of reordering is further enhanced when a storyboard has an explanatory purpose because the structure of a storyboard outlines the key points but in summary form. Mitchell et al. (2011) have noted that “the production of the storyboard is itself a way to go deeply into a discussion, but it is also a way to contain it” (p. 229). The available literature illuminating how storyboards might be used for explanatory purposes can be supplemented here through extant research on explanatory models.

**Explanatory models**

According to the Oxford English Dictionary, a *model* is “a representation in three dimensions of proposed structure etc.” although the common usage of the word ‘model’ has since abandoned any requirement for models to have three dimensions.¹ Caws (1974) discussed how the structure of a model is itself more indicative than the elements within the model. For example, a model house made of matches or cardboard resembles the function of bricks rather than the bricks themselves. This emphasis on structure is an affordance of models in general, because the structure is literally embodied within the model. Caws was careful to note that “a structure is not a

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¹ Marr (1982) also introduced the term 2½ dimensions to describe instances where two-dimensional surfaces are rendered in such a way as to assist the perception of depth.
set of entities but a set of relations” (1974, p.3). Caws also coined the term *explanatory model* as “one of the scientists’ mental structures” (ibid, p. 5) thus making a distinction between mental constructs and *representational models*, the latter of which he saw as a description of relationships.

In cognitive science and educational psychology, an explanatory model is simply a representation that has an explanatory purpose (Floridi, 2011; Gilbert, Reiner & Nakhle, 2008; Hubber, Tytler & Haslam, 2010; Treagust, Chittleborough & Mamiala, 2002; Wiser & Smith, 2008). The current study uses ‘explanatory model’ in this same tradition. A ‘cognitive model’ (Evans, 2006) however, is not an artefact but a conceptual knowledge structure that lists the “semantic potential that lexical concepts provide access to” (p. 496). Gemino and Wand (2004) and others have used the term ‘conceptual model’ as a synonym for explanatory model. Of interest is the way in which the creator of a conceptual model is forced to confront their own understanding of their subject matter. Gemino and Wand (2004) further noted how “discrepancies between a person’s understanding of the system, and the model used to represent the system leads to issues in both creating and interpreting” an artefact (p. 256).

One such issue is that all explanatory models have inherent limitations. Bonini’s paradox has some relevance here. The paradox, named after Stanford business professor Charles Bonini, proposes that the more complete the model, the more difficult it is to comprehend (Dutton & Starbuck, 1971). Hence, the strength of any model is that it should simplify the subject matter by leaving out non-essential information. Michael Poole (1995) referred to a similar paradox when describing the limitations of language in relation to concepts and models saying that “every comparison has a limp” (p. 49) as comparisons deal with particulars and are therefore only partial. Hutchins (2012) has also noted that models are selective for the sake of clarity. He described this selectivity as a “filter” (p. 319) where certain elements and relationships are deliberately eliminated.

Within the science education literature, there is a renewed focus on *representation as evidence of learning*, because the creation of models as representations can surface what a child knows (Gilbert, Reiner & Nakhle, 2008; Hubber, Tytler & Haslam, 2010; Treagust, Chittleborough & Mamiala, 2002). This interest has also sought to understand how student generated models can facilitate interactions between students.

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1 Since Kleinman (1980) however, the most common use of the term *explanatory model* is found in healthcare where a patient’s understanding of their condition is often compared and contrasted with a physician’s explanation. Kleinman defined explanatory models as “the notions about an episode of sickness and its treatment that are employed by all those engaged in the clinical process” (Kleinman, 1980, p. 105).
and teachers (Chandrasegaran, Treagust & Mocerino, 2011). During these interactions, the learning process relies on the teacher’s ability to interpret “students’ representations as evidence of their understanding” (Waldrip & Prain, 2013, p. 29).

In application, a Representation Construction Approach (RCA) to learning (Tytler, Hubber, Prain & Waldrip, 2013) uses a pedagogical approach based on the central practice of students making representations and then using these representations as catalysts for conceptual consolidation through classroom discussion. Of particular interest is the emphasis that the RCA places on negotiation and co-construction of meaning. When an artefact has an explicit communicative role and the creator of that artefact is present for dialogue during its creation (rather than relying on interpretation after the fact), the co-construction of meaning revolves around the explanatory purpose of that artefact.

A RCA treads consciously around another issue pertaining to science education, which involves the timing and use of established, canonical representations and the exploratory, creative pursuits of letting students develop their own representations. A RCA has nuanced this issue with a keen interest in representations as a window into mental models as “learning about new concepts cannot be separated from learning both how to represent these concepts and what these representations signify” (Waldrip & Prain, 2013, p. 17). Perhaps the most important premise from the RCA is that representations must be explained and critiqued, as the explanatory purpose of representations is not always self-evident. This resonates with the work of Harrison and Treagust (1996) who made the same point about using metaphors.

**Metaphors and analogies as mediating devices**

The use of metaphors and analogies is a common device for the purposes of explaining one thing by relating it to another. Lakoff and Johnson (1980) have described the *source domain* as the familiar and the *target domain* as the subject for which we are seeking to infer a comparison. For example, when using the metaphor of water to explain electricity, it is assumed that people are quite familiar with the attributes of water as a source domain such as water pressure and water flowing and then some of these attributes are said to be illustrative for the less familiar attributes of electricity, which is the target domain. It is important, however, to remember that metaphors are not explanations. Their value is “more heuristic than analytical and more useful in the context of discovery than verification” (Weiner, 1991, p. 929).
Because metaphors are used to make connections, it is not uncommon to find multiple or even contrasting metaphors, as no metaphor provides a complete analogy.

Petrie (1979) has proposed that metaphors are epistemologically necessary. By this he means that it is by comparing and contrasting one thing to another that knowledge is constructed and shared. Andreou (2013) has also noted that the use of metaphors is a creative act by "linking things that are originally unrelated" (p. 14). Lakoff and Johnson (1980) have emphasised that metaphors are not merely a literary device, but rather, an essential part of thinking and reasoning. Yet others such as Green (1993) have cautioned that the common pedagogical practice of using metaphors to enhance explanations can also be problematic as students often “transfer attributes from the teacher’s analogue to the target” in a literal sense (Harrison & Tregust, 1996, p. 511).

According to Zittoun, Gillespie, Cornish and Psaltis (2007), “metaphors have their affordances, their side-effects, and their unexpected consequences” (p. 225). One problem then, is that students are often not told which parts of a metaphor are relevant and which parts are not or how one concept can be mapped onto another. Fichtner (1999) is insightful here by noting that an important aspect of working with metaphors is knowing how to handle them as, “metaphors are not illustrations of empirical facts, but rather visual images of theoretical relationships and, thus, a means of reflection” (p. 323).

Both deliberate instructional metaphors and figurative language are often misunderstood by children as language operates on a “horizontal (sequentially ordered) plane as well as a vertical (associational or metaphorical) plane” (Manning, 2003, p. 1023). Metaphors involving representations of physical objects appear to be particularly problematic for children. Deloache and Burns (1993) found that the ability of children to recognise the symbolic qualities of an object is a skill that develops throughout childhood.

Ackermann (1991) noted that children often interpret metaphors literally to the detriment of their own learning as, “drawings are not analogues of the ideas that they express” (p. 286). This issue is relevant to the current study as it shows how the mediating object (i.e., metaphor, representation or both), which is supposed to be a catalyst for conceptual consolidation, is often a stumbling block without clarification through sufficient dialogue. The following two examples bear this out in terms of how children can be prone to misconceptions when presented with metaphors:
1. Ackermann’s observation (1991) was in the context of revisiting Piaget’s water level experiment. One of her student’s drew a ribbon around a bottle to depict the water level inside the bottle and then proceeded to treat the drawn ribbon as an actual ribbon rather than the water level.

2. Butler (1998) recounted a story about a primary school teacher who boiled a kettle of water in class to show the water changing from a liquid state to vapour. When children were then asked to draw how this could occur in nature (assumedly with lakes and clouds and so on), one child drew a kettle placed out in the wilderness. The misunderstanding only became apparent through the child’s drawing, as the teacher had assumed that the children understood that the kettle was a metaphor.

The examples of the water level ribbon and the kettle in the wilderness show that the problem, in each case, occurred when the representations were taken literally. The line on the water bottle only became a metaphor when it was drawn as a ribbon. The kettle in the wilderness might well have been the result of only presenting the child with a single metaphor. The use of multiple metaphors helps in such instances, as children are orientated to the fact that metaphors are only intended to have particular points of similarity in each instance. The relevance and implication of this for the current study is that in a well-designed explanatory animation, when metaphors and analogies are used, they must be explained and not merely presented, as the intended inferences are usually not self-evident. Furthermore, “the point at which the analogy breaks down must be recognised by students to avoid wrong inferences on, or oversimplification of, the new concepts” (Mason, 1994, p. 289).

Metaphors, images and diagrams are particular types of signs known as icons. Teachers can mediate the understanding of metaphors by discussing icons and the process of iconicity by metaphorically mapping concepts across modes through drawing, sequencing and reflection. Nersessian (2008) noted that this process of mapping need not involve a direct correlation for all of the particulars but, rather, as “sources for constraints” (p. 28). Accordingly, the combination of constraints and direct mapping is then the basis for model-based reasoning (Nersessian, 1984, 2002, 2008, 2012), where models are constructed and critiqued to understand concepts, as “conceptual change involves such reasoning” (2008, p. 16). Nersessian built her theory through dialogue with others such as Clement (1988) who proposed that, when dealing with metaphorical comparisons, both the correlation and constraints of particulars are more than associations, but rather, “transformations” (Nersessian, 2008, p. 211). This transformation is not initially about the content itself, but rather a person’s
understanding of that content. Ultimately, the content is also transformed as evidenced in the person’s updated explanatory model.

There would appear to be some commonality between knowledge transformation and \textit{transmediation}. Transmediation is the process of translating content from one modality to another (Broudy, 1977; Suhor, 1984). Siegel (1995) has suggested that transmediation always involves “an enlargement and expansion of meaning, not a simple substitution of one thing for another” (p. 457). Compared to metaphor, where core elements pertaining to a conceptual topic might be identified and then explained by mapping between the particulars of the target and source domains, transmediation is seen to be a catalyst for conceptual change because the core elements (i.e., variables) are translated from one modality to another. It is this notion of translation that is the hallmark of transmediation rather than the actual modalities that are involved. Vygotsky (1962) made a similar observation about semantics when he noted that thought can change into words and then back to thought and vice versa as, “word meanings are dynamic rather than static formulations” (p. 124).

The fluidity of these transmediations might appear to infer that conceptual change is an ongoing process that has no final destination point. Yet, as implied in the research question within this study, a final destination might involve the articulation and consolidation of conceptual understanding. However, rather than considering transmediation and conceptual change as infinite versus finite, a more suitable viewpoint might be to theorize conceptual consolidation along a continuum (Wilensky, 1991) between the abstract and the concrete.

\textbf{The abstract and the concrete}

In the seminal book \textit{Constructionism}, Turkle and Papert (1991) proposed a “re-evaluation of the concrete” (pp. 161-192) where they questioned the nature of abstract thinking. This re-evaluation is clearly in reference to Piaget’s stage theory (Piaget & Inhelder, 1969), which suggested that the \textit{concrete operational stage} (most clearly associated with primary school children), preceded the \textit{formal operational stage} which is characterised by abstract reasoning. Piaget saw abstract reasoning as the hallmark of secondary school children coming of age as they grew into adulthood. Piaget’s theory of cognitive development is now widely critiqued but his categories still provide useful vocabulary for discussion.
In his chapter “Abstract Meditations on the Concrete”, Wilensky (1991) takes this re-evaluation further by suggesting that everything is abstract until you understand it. The term “concretizing” (Wilensky, 1991, p. 194) was then used as a metaphor for understanding. Difficult concepts gradually set when students are able to represent, manipulate and interact with them. “Concepts that were hopelessly abstract at one time can become concrete” (ibid, p. 198).

An implication of Wilensky’s view is that abstract and concrete are not fixed categories to which different types of knowledge intrinsically belong. Instead, these categories could be more accurately described as different ends on a learning continuum across which meaning can be consolidated and represented. The relative movement of ideas from abstract to concrete depends on the comprehension of each concept, by each person, on a case-by-case basis. This notion is not new, as Dewey made the same point over 100 years ago when he commented on the interplay between concrete and abstract concepts as being “relative to the intellectual progress of an individual; what is abstract at one period of growth is concrete at another” (Dewey, 1910/1997, pp. 136-137).

Davydov (1990) also critiqued the notion of a fixed progress from concrete to abstract under the heading “The method of ascent from the abstract to the concrete” (1990, pp. 128-138). Of interest here is not whether abstract and concrete are constituted in a vertical relationship but, rather, that new ideas are metaphorically out there and that they become increasingly concrete as they move towards the learner and become internalised. Similarly, Vygotsky (1987) described the relationship between concrete and abstract as a two-way phenomenon depending on the context. He saw conceptual consolidation as proceeding from the abstract to the concrete whereas theorising was served by the capacity for abstraction:

Conduct formation…does not occur through a gradual transition from the concrete to the abstract. The reverse movement, the movement from above to below, from the general to the particular or from the top of the pyramid to its base is as characteristic of this process as is the reverse movement toward the pinnacle of abstract thinking (p. 128).

Having considered some of the modalities and variables involved with conceptual learning, some mention is required about the animation medium itself, as this provided the context for the current study.
Learning from viewing explanatory animations

Animation, like multimedia, is not a single mode of representation but a medium or composite mode which is capable of combining imagery with sound and, of course, movement. Explanatory animations (i.e., animations containing a narrated explanation) are part of the visual narrative genre. According to Wright, (2010), “it is the integration of three modes in consort - graphic, narrative and embodied - that makes visual narrative a powerful source for children’s learning, representational thought and creativity” (p. 20).

The literature on animation in education revolves around the central issue of how effectively the viewing of animations can be used to facilitate learning. Lowe (2001) was convinced that the potential of animation in education is enormous but expressed concerns that poorly designed examples could result in this important medium being dismissed as a mere gimmick. “If animation is poorly designed or applied, it may create more learning problems than it solves” (Lowe, 2001, p. 8). Animation can combine vision and sound with great potential and flexibility but these elements are often employed as a novelty that can assault our senses (Ellis, 2012). An implication from this is that instructional multimedia should be carefully designed to only enhance relevant elaboration.

The objective of an explanatory animation is for the author to communicate and explain their topic. Hence, the focus must be on the explanation and not simply on the showing. Tversky et al., (2008) has suggested that this emphasis on showing rather than on telling, might account for the underwhelming impact of explanatory animations as an educational medium. Animation design advocates such as Mayer (2001, 2005, 2009) have sought to remedy this situation by formulating a growing list of design guidelines to improve educational outcomes by improving instruction. However, it must be noted that both the animation critics and the animation advocates make the assumption that professional animators are creating the explanatory animations and that children comprise the audience for such animations.

Furthermore, researchers who have studied the effectiveness of the animation medium, and how this medium might impact learning, have primarily focused on the viewers of the animations, rather than the authors of the animation. The current study has sought to address this by focussing on the conceptual consolidation of the animation author and how meaning can be mediated through the creation of multimodal texts. Hubscher-Younger and Narayanan (2008) described the idea of learning through the process of making explanatory animations as tantamount to
“turning the tables” (p. 235). Clearly, there is a need for more research into the potential for how this making process might augment the conceptual growth of the author.

**Design principles for teaching with animation**

One leading exponent of explanatory animation design guidelines is Richard Mayer. As the editor of *The Cambridge Handbook of Multimedia Learning* (2005), Mayer defined three key terms in his “Introduction to Multimedia Learning” (paraphrased from p. 2):

- **Multimedia**: The presentation of words and pictures\(^1\) together.

- **Multimedia instruction**: Presenting words and pictures with the intention to promote learning.

- **Multimedia learning**: Building mental representations from words and pictures.

Mayer’s (2001) multimedia theory is known as the “cognitive theory of multimedia learning” (p. 3). Table 2.2 combines Mayer’s (2001) chapter headings with synopses of his seven multimedia principles.

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\(^1\) Mayer’s definition of ‘multimedia’ implies that he restricted his model to these two modes of words and pictures but he also included audio (as both sound and narration), movement, colour, proximity and temporality as shown in Table 2.2.
Table 2.2
Mayer’s (2001) multimedia theory

<table>
<thead>
<tr>
<th></th>
<th>Multimedia principle</th>
<th>Students learn more from words and pictures than from words alone.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Spatial contiguity principle</td>
<td>Students learn more when corresponding words and pictures are presented close together, rather than far apart, on a page or screen.</td>
</tr>
<tr>
<td>3</td>
<td>Temporal contiguity principle</td>
<td>Students learn more when corresponding words and pictures are presented simultaneously rather than successively.</td>
</tr>
<tr>
<td>4</td>
<td>Coherence principle</td>
<td>Students learn more when extraneous words, pictures, and sounds are excluded.</td>
</tr>
<tr>
<td>5</td>
<td>Modality principle</td>
<td>Students learn more from animation and narration than from animation and on-screen text.</td>
</tr>
<tr>
<td>6</td>
<td>Redundancy principle</td>
<td>Students learn more from animation and narration than from animation, narration and on-screen text.</td>
</tr>
<tr>
<td>7</td>
<td>Individual differences principle</td>
<td>Design effects are stronger for low-knowledge learners than for high-knowledge learners and for high-spatial learners than for low-spatial learners.</td>
</tr>
</tbody>
</table>

Mayer’s seven principles of multimedia learning were expanded to twelve principles in his 2nd edition in 2009 and there appears to be no end to the actual number of principles that could be developed. For example, the voice principle states that “People learn better when the narration in multimedia lessons is spoken in a friendly human voice rather than a machine voice” (Mayer, 2009, p. 268). Whilst this new principle was validated through empirical testing, I believe that the explanatory power of Mayer’s theory was best expressed in his original (2001) articulation. The new voice principle could have been logically implied from the original coherence principle that aims to eliminate distractions. Hence, for the purposes of this study, these seven principles will be used.

Mayer has been careful to stress that viewers of an animation must construct their own mental representations of the material that they are viewing. Although the viewer of an animation might appear to be passively watching, Mayer insists that learning can only occur through mental engagement with the words and pictures. This emphasis on constructing mental images, however, should not be equated with constructionism as Mayer’s experiments were measuring participants’ retention and transfer when viewing professionally made animations rather than participants’ building artefacts of any kind.
It is here that the current study deviates sharply from Mayer’s established principles as the participants in the current study were engaged in dialogue with me throughout the project to negotiate meaning. This dialogic approach is consistent with Prain and Tytler’s (2013) finding that when students generate their own representations, teacher and student negotiation of meanings are “evident in verbal, visual, mathematical and gestural representations” (p. 11). Such negotiations of meaning characteristically focus on issues such as those discussed in Lowe’s (2001) guidelines for creating educational animations (see Table 2.3).

Table 2.3
*Lowe’s animation creation guidelines* (paraphrased from Lowe, 2001, pp. 6-7)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Analyse the dynamic situation and its events</td>
</tr>
<tr>
<td>2</td>
<td>Select the graphic entities, relationships and properties</td>
</tr>
<tr>
<td>3</td>
<td>Determine main events</td>
</tr>
<tr>
<td>4</td>
<td>Devise a presentation sequence</td>
</tr>
<tr>
<td>5</td>
<td>Construct a temporal structure</td>
</tr>
<tr>
<td>6</td>
<td>Cue the critical information</td>
</tr>
</tbody>
</table>

There are some fundamental differences between the principles of Mayer (2001) and the guidelines of Lowe (2001). Mayer focuses on the relationship between modes along with some spatial-temporal principles surrounding these; Lowe focuses more on events, sequences and structures. Lowe’s guidelines focus on practical applications to assist and guide the animation author through the actual stages of animation creation. Mayer’s principles function as a reference tool for making decisions about particular design elements of an animation.

An important assumption that both Mayer and Lowe make is that the animation authors already understand their subject matter. Yet the current study sought to explore whether the process of making explanatory animations itself causes the author to refine and deepen their own understanding of their subject matter. This specific exploration was conceptualised through Vygotsky and Sakharov’s dual stimulation method.
Concept formation and the dual stimulation method

Daniels (2012) has defined Vygotsky and Sakharov's dual stimulation method as an experimental approach where people are placed in a situation where "a problem is identified and they are also provided with tools with which to solve the problem or means by which they can construct tools to solve the problem" (p. 822). The first stimulus (i.e., problem) and the second stimulus (i.e., tools) are predetermined and so the point of this method is to understand the effect of the second stimulus on the first. According to Giest (2008), the cornerstone of the dual stimulation method is to investigate “human psychological functions in the process of their development by creating the conditions that mainly cause the development" (p. 103).

Vygotsky’s interest in conceptual change was inspired by one of the pioneers in this field, Narziss Ach (1871-1946). Vygotsky (1987) described Ach’s research as opening up an “entirely new plane” (p. 122) that “created the potential for studying the process of concept formation” (ibid). Vygotsky, however, found flaws in Ach’s method and believed that Ach had failed to offer a causal-dynamic explanation for the formation of concepts. Vygotsky (1978) considered the use of tools as mediating devices within the dual stimulation method as being “important because it helps to objectify inner psychological processes” (p. 75, original emphasis). Subsequently, Vygotsky described his rationale for the dual stimulation method as being built on the following six principles (Vygotsky, 1987):

1. The task is presented fully to the student in the initial moments of the experiment.
2. The establishment of the task or emergence of the goal is a prerequisite for the development of the process as a whole.
3. The means are introduced gradually.
4. The stimulus-sign or word constitutes the variable.
5. The task is the constant.
6. Depending on how the word is used, depending on its functional application, we are able to study how the process of concept formation proceeds and develops (p. 128, numbers added).

Using the terminology from Table 2.1, the first stimulus was the dependent variable and the second stimulus was the independent variable. In other words, the second stimulus was introduced to measure or observe the effect on the first variable. The current study deviated slightly from Vygotsky’s and Sakharov’s use of this method in relation to the timing of the introduction of the second stimulus where the “means are
introduced gradually” (i.e., principle three).¹ In the current study, the first stimulus (i.e., the task of explaining a topic) was augmented with the second stimulus (i.e., explanatory animation creation) almost immediately. There were two reasons for this:

1. Vygotsky’s criterial interest when using the dual stimulation method was always on the second stimulus (Wertsch, 1991).
2. The children had chosen to be involved in this study because they wanted to make an animation and were eager to get started.

The dual stimulation method and particularly Vygotsky’s interest in mediation, has inspired others such as Engeström (1987), to develop more comprehensive models of activity such as Cultural Historical Activity Theory (CHAT). In this study, the dual stimulation method was foundational for posing the research question, and CHAT provided the framework for answering it.

**Cultural Historical Activity Theory (CHAT)**

As the children’s conceptual task involved multifaceted activities, activity itself became an important issue as it provided a context for this research. Engeström conceptualised CHAT with a focus on knowledge creation stating that, “the object of activity is a moving target” (Engeström, 2001, p. 136). Unlike a scientific experiment, where variables could be determined in advance to ensure that the experiment proceeded with clearly defined dependent and independent variables, the children’s task was to determine what these variables actually were.

Activity Theory is based on the work of Lev Vygotsky and his colleagues A. R. Luria and A. N. Leontiev. Vygotsky's founding contribution to CHAT was through his understanding of mediation through the use of tools. Kaptelinin (2013) has suggested that in Vygotsky’s psychological framework, perhaps mediation was “the most important concept of all” (p. 206, original emphasis). CHAT was selected as an analytical framework for these data as a dynamic of Engeström’s theory is that, “processes of knowledge creation are intertwined and co-evolve with human practical activities” (Hakkarainen, Palonen, Paavola & Lehtinen, 2004, p. 119).

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¹ Vygotsky’s (1987) third principle was illustrated through an example with Leontiev and Luria (reported by Radzikhovskii, 1979; Wertsch, 1991) where patients with Parkinson’s disease were asked to walk across a room. When pieces of paper were placed on the floor as mediating devices to approximate footsteps, the patients were able to attempt their passage more easily. Delaying the introduction of the paper was necessary to show that the patients were unable (or reluctant) to attempt the journey without the introduction of the second stimulus.
Figure 2.1 is Engeström's first-generation CHAT model based on Vygotsky’s notion of tool mediation. The use of a triangle shape is an attempt to capture the system qualities of the activity, also known as an activity system.

Figure 2.1. First-generation CHAT model.
(Source http://www.helsinki.fi/cradle/chat.htm Used with permission.)

Engeström (1987) expanded the first-generation CHAT model into a second-generation model by including Leontiev's (1981a) additional categories of rules, community and division of labour. This new model allowed Engeström to present a framework for studying activity, as the second-generation model was sufficiently sophisticated to contextualise activity as a societal rather than individual phenomenon. Figure 2.2 shows Engeström’s second-generation model and also suggests an outcome for the model in relation to the object.

Figure 2.2. Second-generation CHAT model.
(Source http://www.helsinki.fi/cradle/chat.htm Used with permission.)

Of additional interest here is that Engeström had substituted ‘meditating artefact’ with ‘instruments’ at the top of the triangle. I would like to address this by presenting my
own contextualisation of Engeström’s second-generation model by using categories from the current study as Figure 2.3.

![Figure 2.3](image)

**Figure 2.3.** A revised CHAT model using categories from the current study.

Figure 2.3 equates ‘tool’ with ‘computer’, which would appear to be congruent with Engeström’s ‘instrument’ in his second-generation model. Of greater significance is that the ‘object’ in the current study (i.e., a storyboard as the embodiment of the explanatory animation creation process) has become the ‘mediating artefact’. This effectively collapses Engeström’s first-generation CHAT model, as three points have become two (see Figure 2.1). Vygotsky’s notion of tool use was intrinsic to his understanding of mediated action, as a tool only becomes such when it is used. As Dron (2012) has argued, “a tool separated from its use is meaningless: a stick lying in a forest is just a stick” (p. 25). Tools can be tangible or cognitive (Cross, 2010; Vygotsky, 1981) but artefacts can also function as tools if they are used for a purpose.¹ According to Christiansen (1996), an artefact attains its qualities of function when it is integrated into an actual activity. In other words, “to become a tool is to become part of someone’s activity” (p.177).

¹ The notion of an artefact functioning as a tool is discussed further in relation to data from the current study in Chapters 4, 5 and 6.
Henley, Caulfield, Wilson and Wilkinson (2012) attributed the significance of Engeström’s second-generation model as enabling “both individual learning processes and social interaction to be viewed simultaneously” (p. 506) due to the system qualities of the model. The true value of CHAT for the current study is that it provided a sufficiently flexible framework to conceptualise both the activity (i.e., animation creation through discussion, representation and reflection) and the product (i.e., the evolving artefact).

Engeström (2001) evolved his CHAT framework into a third-generation model, which depicts a pair of the second-generation models to represent two interacting activity systems. The theoretical interest in this model (see Figure 2.4) lies in the interaction between the two models which is shown as a potentially shared object:¹

![Figure 2.4. Third-generation CHAT model.](http://www.helsinki.fi/cradle/chat.htm)

The main significance of the Engeström’s third-generation CHAT model for the current study involves defining the unit of analysis as the re-enactment of activity over time that can occur when people collaborate on a project. The unit of analysis is important because, as Newman, Griffin and Cole (1989) have noted, “we can analyse specific aspects of the functional system in any particular investigation, yet the unit of analysis itself retains the critical components for change” (p. 72).

Patchen and Smitheny (2014) have further noted the system dynamics of the CHAT model. They describe the duality of the model as a bifocal lens for understanding activity in context:

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¹ One possible interpretation and application of the potentially shared object being time will be discussed in Chapter 5 in relation to the current study.
Fundamentally, CHAT acts as a “bifocal” analytic lens, keeping an eye on parts, elements, or moments of praxis, while attending to the context in which these moments occur. The strength of this type of lens resides in its capacity to reveal the relationships between the parts and the whole, that is, the interconnected nature of activity in the classroom as it unfolds in real time and real working praxis (p. 607).

A common view within the CHAT literature is that activity itself is the unit of analysis (Hashim & Jones, 2007) and that the purpose of analysis is to understand human actions. Vygotsky (1962) understood a unit as “a product of analysis which, unlike elements, retains all the basic properties of the whole and which cannot be further divided without losing them” (p. 4). According to Blunden (2009) “The rest of Vygotsky’s work testifies to the fact that the shared use of cultural tools of any kind was Vygotsky’s unit of analysis” (p. 10).

Engeström and Miettinen (1999) made a similar claim to Vygotsky by suggesting that “culturally mediated human activity” (p. 9 original emphasis) or even the “activity system” itself (ibid, original emphasis) are strong candidates for the unit of analysis in Activity Theory. Engeström and Miettinen then proceeded to list the same six categories from the second-generation CHAT model (i.e., tools, subject, object, rules, community and division of labour) as the minimum elements. Blunden (2009) brings Engeström and Miettinen’s position into question by asking how any one of these elements can be understood independently of the activity in which it is expressed by arguing that if “the ultimate reality we are dealing with is activity, then every one of these concepts is derivative of the concept of activity” (p. 16).

Blunden’s (2009) preferred unit of analysis is project collaboration. He emphasised the interrelationships through an analogy where “the atom is the system for particle physics, but unit for molecular physics” (p. 24) and where “project collaboration is the system for psychology, but the unit for social science” (ibid). Blunden (2009) sees projects as being both the means and the ends of activity as projects have teleological properties due to their objectives:

A project mediates collaborative activity, but it is not an artifact. All activity is artifact-mediated, but people can cooperate in a project by pursuing the common aim even if they are not in direct communication. The use of artifacts remains a part of collaborative projects, but the key mediator is the project itself, however it is represented (p. 18).

The following list summarises these various positions about the unit of analysis and shows an expanding concept of unit according to different perspectives:
• Vygotsky (1978): Tools
• Leontiev (1981b): The activity for which tools are used
• Cross (2010): Activity system
• Blunden (2009): Project collaboration

These different perspectives, however, need not be seen as an evolution of thought. Rather, the unit of analysis can be whatever is appropriate for the research being conducted. This is in keeping with Thorne’s (2004) view that CHAT is not so much a theory per se but a conceptual framework for understanding human activity.

A final point about CHAT is that the activity system, like all systems, affords various perspectives on that system according to focus of the researcher. As noted by Patchen and Smithenry (2014), “CHAT directs attention to the generative process of activity - one element at a time, but never just one element alone” (p. 610). The system perspective helps define the scope of a project but the unit perspective allows for the artefact, or parts thereof, to be seen in terms of their generative, mediating role between existing knowledge and new knowledge creation.

According to Dang (2013), “the driving force of change and development in activity systems, is internal contradiction” (p. 48). Understanding these contradictions requires the researcher to have a close proximity to the activity system, indeed, to become part of the activity system. Activity itself is then brought back into focus in the context of collaboration and co-authorship. In the current study, activity and the co-construction of artefacts was conceptualised through Vygotsky’s zone of proximal development.

Vygotsky's Zone of Proximal Development

Vygotsky's (1978) Zone of Proximal Development (ZPD) is usually defined as a situation where a learner can extend their learning through interaction with a more capable assistant. In my discussion of ZPD I commence with Wood, Bruner and Ross’ notion of scaffolding (1976) and how it might function as a mediating device.

1 Internal contradictions are also an important part of the change laboratory technique developed by Engeström, Virkkunen, Helle, Pihlaja and Poikela (1996). The current study, however, did not utilise the change laboratory technique as that technique is used primarily to affect change at the institutional, organisation level.
The notion of scaffolding was introduced as a metaphor for guidance and assistance within the ZPD. As with most metaphors, there can be unintended implications that must be identified (Pimm, 1981). There appears to be at least three issues pertaining to scaffolding which have been abstracted from the metaphor itself rather than the ZPD:

1. The first abstraction is that scaffolding is temporary because scaffolding is only in place during construction. According to Holton and Clarke (2006), “when the building is finished or the renovation complete, the scaffolding is removed. It is not seen in the final product” (p. 129). Yet the capacity for growth from a more capable peer will always be present as the phrase more capable peer opens up the more competent person to include a mentor rather than just a child/adult relationship. Although Vygotsky focused the ZPD on children, “the concept can be elaborated throughout childhood” (Moran, 2010, p. 143). John-Steiner (1985) also shares this view and recounts a story of the composer Stravinsky being mentored as a young adult composer as an example of the ZPD.

2. The second abstraction is the notion of “closing the gap” (Shepard, Hammerness, Darling-Hammond & Rust, 2005, p. 279) within the ZPD, which is a common expression used to describe a child's growth or progress in ability. Venn diagrams of the ZPD show the child's ability as the smaller shape within the larger shape that represents their potential for learning. It follows that any growth experienced by the student doesn't close the gap but rather expands the boundaries.\(^1\)

3. The third abstraction involves self-scaffolding (Holton & Thomas, 2001). Holton and Clarke's (2006) notion of the epistemic self takes self-scaffolding even further by suggesting that self-scaffolding is “essentially equivalent to metacognition” (p. 128). Self-scaffolding implies that the scaffolding originates with the child. According to Connery, John-Steiner and Marjanovic-Shane (2010), children become increasingly competent learners by independently applying the scaffolds set up by others. This notion also affirms the inherent unity between the act of creating the zone and the zone itself. “The activity of creating the ZPD, of creating the environment for development, is inseparable from the development that occurs” (ibid, p. 203).

\(^1\) The idea of expanding the boundaries within the ZPD is discussed further in Chapter 4 and represented diagrammatically as Figures 4.1 and 4.2.
Development through spontaneous interaction within the ZPD is what Saye and Brush (2002) have termed soft scaffolding as distinct from prepared interventions which they term hard scaffolding. There is also a mediating role for artefacts within the ZPD (Thompson, 2013). The mediation of learning through artefacts can also be applied to adult interactions, such as when a University lecturer provides written feedback to a doctoral student on a draft of their thesis. When the student edits their thesis under the guidance of their supervisor’s notes, they are working within the ZPD through the mediating device of the notes.

The ZPD is a learning situation where students can experience profound growth because their needs have come into sharp focus in ways which they can enact and understand. Vygotsky (1978) wrote:

> We propose that an essential feature of learning is that it creates the zone of proximal development; that is, learning awakens a variety of internal developmental processes that are able to operate only when the child is interacting with people in his environment and in cooperation with his peers. Once these processes are internalized, they become part of the child's independent developmental achievement (p. 90).

Such learning dynamics often result in shared learning for both the teacher and student. When both the student and the teacher are learning they could be said to enter a "mutual zone of proximal development" (John-Steiner, 2000, p. 177) as collaborative partners. Sutter (2001) has captured this dynamic with his term mutual performance:

> It is like a dance, experienced people are leading, and everyone is taking part. Interpersonal processes of the dance are transformed into psychological processes also for the allegedly more knowledgeable persons; also they will learn and develop (p. 64).

Another way to harness the potential of the ZPD is by personalising learning activities to match the interests and potentials of the child as suggested by Wright (2011):

> A serious interest in children’s semiotic dispositions and their sign-making processes and messages can lead to pedagogies, curricula and momentous projects that evolve from and are matched with the potentials and abilities of the child (p. 172).

Newman, Griffin and Cole (1989) speak of a construction zone within the ZPD where, "children’s actions get interpreted within the system being constructed with the teacher" (p. 63). Sutter (2001) credits Newman, Griffin and Cole’s statement as solving a learning paradox about conceptual structures. The paradox is about how a child’s
simple psychological structure can ever get transformed into a more complex structure. The resolution of the paradox is that there is good reason to believe that “psychology does not reside only within a person’s skull, it take[s] place between people too, and between people and their artifacts” (Sutter, 2001, p. 43).

The current study used storyboarding and explanatory animation creation as a context for the ZPD. It was hoped that the creation of the ZPD might enhance the process of conceptual consolidation for the young animators through their active participation in this multifaceted task. The ZPD is often depicted as a Venn diagram where the helper’s knowledge is the outer shape encompassing the smaller child’s knowledge as the inner shape. Venn diagrams are useful for making such comparisons but the following section discusses schematic diagrams and their affordances as conceptual metaphors for understanding specific topics.

**Schematic diagrams as conceptual metaphors**

A recurring theme throughout much of the conceptual change literature (from both cognitive science and educational psychology) is that the conceptual change process can be characterised as an act of classification using perceptible attributes and features (Chi, 2008; Virkkunen & Ristimäki, 2012). This emphasis on classification is analogous to the use of Venn diagrams. Tversky, Heiser, Mackenzie, Lozano and Morrison (2008, pp. 280-281) however, suggested a more useful way to understand concepts through the metaphor of a schematic diagram. They used a map of a train network as a good example of how only the salient points are included, thus providing a conceptual focus. Yet, each train stop on the diagram is represented as being equidistant and the lines are all drawn as if they're straight because minor deviations in distance and position are not important to the schema. “Concepts are given meaning according to the image schematic structures with which they are associated” (Andreou, 2013, p. 16). Hence, in the train network example, identifying relevant variables and relationships between these variables is a system perspective.

Conceptually (in terms of content), schematic diagrams are deliberately selective rather than exhaustive because they are models and function according to their ability to convey essential information. *Multimodally* (as representations), schematic diagrams are the result of representational choices to only include essential information, as meaning is determined and articulated at the design stage and then conveyed accordingly “to make abstract or complex information graphically communicative”
(Andreou, 2013, p. 12). In other words, an affordance of schematic diagrams is that both the conceptual content and representation of that content is subjugated to the intent of providing clear and effective communication.

The methodological implications from the schematic diagram metaphor would appear to be immediately applicable to the process of explanatory animation creation as a mandate to *keep it simple*. Prioritising communication also resonates with Einstein’s guideline to "Make everything as simple as possible but not simpler". For primary school children attempting to understand and explain novel topics using unfamiliar animation techniques, this is good news.

**Summary**

Conceptual consolidation was a key theme in this literature review. Although the emphasis of the conceptual change literature was on classification, the importance of mental models established some common ground with the current study as the emphasis shifted towards the creation of imagery. A continuum between concrete and abstract was also discussed, where new ideas were seen to begin as abstract notions that become increasingly concrete, as they are understood.

There was also a consideration of the system qualities of concepts and how the essence of a concept might exist within the core relationships between the constitutive variables. Likewise, it was also suggested that meaning is afforded greater clarity by excluding non-essential and distracting information. Both of these guidelines require the communicator to become a pedagogical decision maker and thus determine the essential nature of their topic, much like the creation of a schematic diagram.

The multimodality literature provided the vocabulary for the construction of artefacts that find meaning in contexts beyond the written word. An investigation of multimodal affordances led to the conclusion that storyboards are semiotic tools for cross-modal cognition using tangible resources. This conclusion has support from the literature, but this support was inferred from other practices such as student-constructed representations for specific conceptual and pedagogical tasks (by information modelling in secondary-school science curricula).

Storyboarding and explanatory animation creation is clearly a multifaceted task due to the inherent conceptual and technical design issues. It would appear that student-generated explanatory animation creation, however, is not a common task, particularly
in primary school settings and certainly not as represented in the literature. The literature about such a task, or lack thereof, is a blind spot that can be accounted for by the assumption from both the animation design advocates and the animation effectiveness sceptics, that the explanatory animation creation task is the exclusive domain of professional animators. In the current study, Vygotsky’s (1978) ZPD was seen as a way to extend the children’s ability to participate in the explanatory animation task, but also a way to afford me, as the researcher, additional insights into the children’s activity by entering this zone with them.

Lowe and Schnotz (2014) have noted that “animation is distinct from video in that it is not the result of merely capturing images of the external world - rather, it is the product of deliberate construction processes such as drawing” (p. 515). These construction processes were seen as continuing in the tradition of constructionism due to their conceptual content and use of computers as mediating tools. Vygotsky and Sakharov’s dual stimulation method provided a rationale to link the anticipated conceptual gains of this project to the animation task itself. CHAT provided both the vocabulary and perspective to understand conceptual change and artefact creation as recursive elements within a collaborative project environment. Chapter 3 will now address the methodological issues that shaped the explanatory creation process throughout the evolution of this case study.
Chapter 3. Research methodology

In a very real sense, every piece of research is unique and calls for a unique methodology. We, as the researcher, have to develop it (Crotty, 1998, pp. 13-14).

Introduction

Several important decisions were made leading up to the commencement of formal action research that shaped the current study. I will recount these decisions through a theoretically informed autobiography of the research methodology. Mitchell, Theron, Smith and Stuart (2011) introduced the notion of an “autobiography of the method” (p. 1) based on Miller's (1995) autobiography of the research question.

A key issue in the current study is the co-construction of meaning. Some background concerning my unfolding understanding of this issue might be helpful here in relation to my role as a Performing Arts teacher. According to Reynolds and Reeve (2002), collaboration creates an optimal learning environment where “a hallmark of students working in collaborative learning settings is the co-construction of meaning” (p. 448). My understanding of the co-construction of knowledge and meaning has significant overlap with related issues such as co-performance and co-authorship.

Around 10 years ago, I was working with our Junior Band of 6 to 8 year-olds rehearsing common songs such as Twinkle Twinkle Little Star. Up until that rehearsal, I hadn’t thought to play along with the children on an instrument, as I was the conductor. When I tried accompanying the Junior Band on bass guitar, I found that I was able to guide the rhythm and chord changes, which helped unify the sound. After I accepted that this co-performance was more beneficial than conducting from out the front, I settled into this new role and found that we could successfully attempt a much more interesting repertoire.

Applying the same principle to our school orchestra had even more of an impact. Staff members and even parents were encouraged to play in the orchestra to model how each section could and should sound. We ended up with staff members on trumpet, saxophone, drums, bass, violin, cello, clarinet and our school principal was our conductor. The staff members would occasionally stop playing to ensure that the children were keeping up with their own parts. Regardless of how well the orchestra played, we were sending another message to the children, which was that music is fun and we choose to play because we enjoy doing so. This interaction and co-
performance resonates with Vygotsky's (1978) idea that “what children can do with the assistance of others might be in some sense even more indicative of their mental development than what they can do alone” (p. 85).

Co-performance eventually became co-authorship through the biennial Short Film Festivals, which I have been staging with primary school children since 2002. At such times, I assist the children in various capacities, particularly with video and audio editing, as these elements can present a steep learning curve for young learners. I have always found that the children appreciated my overseeing of their work as an executive producer, to ensure that everything came together on the big screen at our local cinema.

The current study commenced with the constructionist view that children can participate in profound learning opportunities through the creation of artefacts that are meaningful to them. My own experiences in creating explanatory animations during a Master’s degree entitled “Animating Best Practice” (Jacobs, 2007) had taught me that the author of an explanatory animation is forced to confront and re-evaluate their own understanding of their topic during the countless pedagogical decisions which are made throughout the design process. I theorised that the participants in the current study would also achieve a deepened understanding of their chosen topics throughout the explanatory animation creation process. This working hypothesis and my full-time immersion in the primary school context for over 10 years provided a rationale to commence action research. Some important groundwork had already been conducted during the 2010 Storyboard pilot study that helped establish the scope and framework for the current study.

**The 2010 Storyboard pilot study**

Halfway through the 2010 school year, I had received the necessary ethics approval and was ready to commence the data collection process. This approval was granted after I had articulated the purpose of the study through a *Plain language statement* (Appendix B) and the requirements of the study as articulated in the *Consent form* (Appendix C). In 2010, the first data were collected from eighteen participants who were in Grades 5 and 6. I wanted to capture the background to the decision-making process inherent in the design task so I included directors’ commentaries as an additional source of data. This led to the creation of three video artefacts for each participant:
1. Prior knowledge video
2. Completed explanatory animation
3. Director's commentary

These data, however, became a pilot study. It was at the recommendation of my PhD confirmation committee in March 2011 that I collect additional data to provide more detailed evidence about the process of creating an explanatory animation. Until then, my focus was on the creation and completion of a product rather than an investigation of a process. The data collection process was re-enacted for the current study in 2011 with some important refinements:

1. Student reflections were to be recorded each week rather than just on the completion of the project.
2. The data collection process was to be augmented through the addition of other data sources to provide a weekly snapshot of each child’s progress.

The basic animation technique however, did not change from the pilot to the main study as the guidelines that I had formulated in 2010 had proven to be most useful. Yet the increased frequency of the student reflections affirmed that the process had more theoretical importance than the product. This methodological improvement also affirmed the importance of monitoring change as a key dynamic. As Vygotsky (1978) noted, “to study something historically means to study it in the process of change; that is the dialectical method’s basic demand” (p. 64).

At this point I reconceptualised how the conceptual consolidation of each participant related to existing theoretical models. The children had already been guided by my own definition of a concept being “a system containing variables” so I began to explore the system qualities of concepts. Davydov (1990) was a primary source for this:

The objective connection between the universal and the isolated (the integral and the distinct) emerges as the specific content of a theoretical concept. Such a concept, in contrast to an empirical one, does not find something identical in every particular object in a class, but traces the interconnection of particular objects within the whole, within the system in its formation (p. 119 original emphasis).

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1 A full description and explanation of all data sources is provided later in this chapter.
Action research was an obvious methodological choice, as I wanted to investigate conceptual change in the child participants’ understanding of conceptual topics through the explanatory animation creation process.

**Practitioner action research**

Anderson, Herr and Nihlen’s (1994) book on practitioner action research was titled *Studying your own school*. However Eikeland (2012) is cautionary about de-emphasising the practitioner orientation as a mere checklist for place of employment:

Native, practitioner research opens the door for praxis research although it is often reduced (at least terminologically) to the implementation of conventional research by practitioners and insiders in work-places and organisations (p. 41, original emphasis).

For Eikeland, practitioner action research should be primarily concerned with generating new praxis. According to Somekh and Lewin (2005), “praxis refers to the process of embedding the development of theory in practical action” (p. 347). Although conceptual consolidation provided the theoretical interest in the current study, *animation praxis* was also an important issue because this provided the context for the case study. My empirical space was the Victorian government primary school sector and my local setting was the inner Melbourne school in which I worked. The theoretical and practical aspects of the current study were embedded in the children’s animation creation task.

Action research gives full consideration of the context, setting and proximity of all stakeholders, but the hallmark of action research is *change*. Anderson, Herr and Nihlen (2007), “the most powerful action research studies are those in which the practitioners recount a spiralling change in their own and their participants’ understandings” (p. 42). The cumulative nature of the children’s voice-over scripts was a design choice to capture such instances of spiralling change due to the way that each version of these scripts was left unchanged as a date-based file. As the Storyboard sessions occurred on a weekly basis over a seventeen-week period, the children and I were also making regular reflections that provided further instances of spiralling change. As the researcher, my task was to document and explain these changes as a case study.
Explanatory case study

Norris and Walker (2005) have noted that case studies are an appropriate way to delineate research for naturalistic inquiry because of the importance of context. Yin (2009) has further divided case studies into categories such as descriptive, exploratory and explanatory. From my experiences during the 2010 Storyboard trial, I had already seen how primary school children could deepen their conceptual understanding through the explanatory animation creation task. It was now my job as a researcher to explain how and why this occurs. This provided a rationale to design the current study as an explanatory case study.

Schramm (1971) noted that all case studies share some commonality as they attempt to “illuminate a decision or set of decisions: why they were taken, how they were implemented, and with what result” (p. 6). The research question for the current study asked “In what ways…” which is tantamount to asking both how and why questions. Yin (2014) recommends using an explanatory case study when researching such questions as they involve “operational links needing to be traced over time, rather than mere frequency or incidence” (p. 10). The current study is also a collective case study (Stake, 1995) as each of the children worked on different topics. Their conceptual journeys provided collective insights into the nature of the explanatory animation creation task.

The case study method has been utilised in a plethora of different contexts ranging from the observation of pre-existing phenomena to examples where the researcher makes a deliberate intervention. This might best be conceptualised on a continuum of involvement between observation and intervention as there are differing views about the nature and role of the educational researcher. On one end of the continuum, researchers such as Burns (1997) advocate that the role of the researcher is “to observe social processes as they occur naturally without the intervention of researchers” (p. 301). At the other end of this continuum is practitioner action research such as Vincent (2004) who worked with primary school children who create multimodal texts. Vincent explained his role in that process as a deliberate intervention where he placed himself “in the system” (p. 77) to gain a close proximity to the phenomena under investigation.

In the current study, the mutual co-construction of data created a dynamic that is even further along this continuum due to the issue of co-authorship. Barab and Squire (2004) have also discussed this continuum of involvement and noted that the use of interventions are “opportunities to examine core theoretical issues and explore
learning” (p. 10). When working with the eight children throughout the explanatory animation creation process in the current study, it was precisely these interventions that surfaced the evidence of change, or the perceived need for change for each of children’s understanding of their topic. Some further background is required here about the logistical choices made prior to commencing the data collection process.

**Selecting the eight participants**

As my usual teaching role involved every child in the school coming to our scheduled music classes each week, an initial invitation to be involved in the project was extended to every Grade 5 and 6 child informally during an open classroom discussion. Interested children were then encouraged to register their interest with me at that time or to see me privately to discuss their ideas for an animation topic. There were more applicants than positions for this project, so I used the following criteria to select the participants:

1. Each child’s choice of topic must be rich with learning potential, as the children were encouraged to choose conceptual topics (i.e., topics that require explanation). The suitability of each topic was determined through individual discussions between each child and myself.
2. Each child’s classroom teacher must confirm that they are up-to-date with classroom work and will therefore not suffer adversely from missing regular classroom activities.
3. Parental consent must be given.

I notified each successful participant personally so that I could gauge their enthusiasm to ensure that they were willing to commit to the project. The final eight children chose to investigate the following topics:

- Electromagnetic fields
- How does hair grow?
- Molecular naming conventions
- Satellites
- Sol feige
- Solar cell efficiency
- Stadium design
- Stringed instruments
As the 8 child participants were promised anonymity for their participation throughout the current study, I have assigned pseudonyms for each child. Some utilise rhyme such as “Stadium design” (Ryan) but most use names that share some letters with their topics such as “Electromagnetic fields” (Magnus), “Molecular naming conventions” (Molly), “How does hair grow?” (Harriet) and “Stringed instruments” (Ingrid). The rest of the children’s pseudonyms were formed through association such as “Solar cell efficiency” (Sunny) or more cryptic names such as “Satellites” (Neil Armstrong) and “Sol Feige” (Maria from The Sound of Music).

**Selecting the animation platform**

Microsoft PowerPoint¹ was chosen as a suitable animation platform because it was already installed on all of the school computers and the children were already familiar with it. The idea of using PowerPoint to generate the imagery evolved from observing some Grade 5 boys working with this software for our Short Film Festival in 2006. The boys had discovered that by using the “Insert duplicate slide” function they could then make slight adjustments to the position of any objects in the new slide by using combinations of various auto shapes like basic rectangles, circles and so on.

By quickly pressing *page down* they could animate their graphics at the rate of their button presses. The crude method of manual manipulation used by these boys allowed for longer and ultimately more elaborate sequences. I showed these same boys how PowerPoint can save each slide (frame) separately in various graphics formats such as GIF, JPG and PNG. Because each slide is named sequentially, they can easily be imported and assembled using video editing software. The timing can then be controlled to produce the desired result when these multiple representations are rendered as a stand-alone video file.

Waldrip and Prain (2013) have noted how the creation of multiple representations is important for students if they are to develop conceptual understanding. They have accompanied this assumption with a challenge for teachers to encourage “sequences of representational refinements without unnecessary duplication” (ibid, p. 25). The “Insert duplicate slide” method satisfies Waldrip and Prain’s guideline about minimising effort, as the duplication is an efficient digital process rather than a laborious manual task. Hoban, Nielsen and Carceller (2010) described sequences of representations as

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¹ Coincidently, Fleurke (2011) has noted that the layout and design of the PowerPoint software itself was clearly influenced by the storyboard.
a “semiotic chain” (p. 437) because meaning is infused into the representations, but also into the arrangement of the representations.

The animation sessions

The animation sessions were held during one of my regular, allocated breaks on Thursday afternoons between 2:30 and 3:30 pm in my main teaching room (i.e., the Music room). The eight children were from various Grade 5 and 6 classes so their other classmates were with their usual classroom teachers during these sessions. There were a total of seventeen one-hour sessions.

We used a range of computers but I tried to provide the same machines to each child every week to avoid disruption, as many of the computers were not networked. The eight participants used three desktop PCs, three laptop PCs, one iMac (running as a PC using boot camp) and one MacBook. The wide variety of technology used was not a deliberate attempt to examine the affordances of different platforms but a practical constraint based on what was readily and consistently available in the Music room.

During the first session, I introduced the animation project to the participants by showing the participants some examples of explanatory animations that I had created. These animation examples were viewed to make the point that explanatory animations should be as short as possible, generally not exceeding one or two minutes. These examples encouraged the participants to refine their topics to become quite specific to reduce the demands placed on cognitive load for the subsequent viewers of the completed animations. I moved around the classroom much like any teacher would in a normal classroom setting, but the small class size of eight participants allowed for more extended interactions.

Multimodal data was generated throughout the project, starting with the first session where each child created their own folder. My contribution of ideas to assist the children was both necessary and problematic as it was imperative that I should distinguish my contributions from that of the participants. The only direct contributions that I made (i.e., making changes or contributing imagery outside of the case study sessions) were done in the final days of the project to enable us to complete the final animations in time for the debriefing session. Whenever I amended a child’s PowerPoint file outside a session, I saved the amended file as a new name so we could easily undo my contribution if necessary. For example “Stringed instruments
081211.ppt” became “Stringed instruments 081211b.ppt” (b for Brendan). Each week I created a new folder on my own computer called “Session 1”, “Session 2” and so on to keep all of the related media together. Each child was issued with their own USB drive to back-up their work. These USB drives were then copied into the “Session” folders on my computer.

The twelve data sources that informed the current study will now be detailed in terms of how they were collected, and more importantly, why they were chosen and what I was looking for.

The twelve data sources

The twelve data sources generated throughout the current study served to document the evolution of this project. These sources were centred on the various roles that the children and I had in the co-construction of the animation artefacts. Table 3.1 ascribes these sources as primarily originating from the child or myself as follows:

Table 3.1

<table>
<thead>
<tr>
<th>Children</th>
<th>Researcher</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior knowledge videos</td>
<td>Attendance roll</td>
</tr>
<tr>
<td>Imagery files</td>
<td>Lessons plans</td>
</tr>
<tr>
<td>Voice-over scripts</td>
<td>Researcher reflections in weekly reviews</td>
</tr>
<tr>
<td>Completed explanatory animations</td>
<td>Researcher’s reflexive journal</td>
</tr>
<tr>
<td>Directors’ commentaries</td>
<td>Conceptual consolidation rubrics</td>
</tr>
<tr>
<td>Student weekly reflections</td>
<td>Debriefing sessions</td>
</tr>
</tbody>
</table>

These twelve data sources are further delineated in Figure 3.1, which illustrates the interactive relationships between these sources and how the co-construction of the animation artefacts was not a linear process but rather an interactive process. This Venn diagram also shows whether the data sources were primarily reflective or constructive in nature.
Figure 3.1. Venn diagram of the twelve data sources.

Although there was considerable weaving between student and researcher processes, particularly in relation to the co-construction of the imagery files, voice-over scripts and completed explanatory animations, the twelve data sources will be presented first in relation to the child data sources followed by the researcher’s for the purpose of clarity. This, however, is not meant to be interpreted as a sequential pathway, but instead, a back-and-forth iterative process.

Extracts from the twelve data sources described below are included in the portraits of the children in Chapter 4. These portraits contain the data analysis for each child where I provide a behind the scenes account of the current study and how it evolved according to each child’s conceptual journey. The twelve data sources will now be described as an introduction to what they are and also to provide a rationale as to why these sources were collected.
Prior knowledge videos

Each student recorded a prior knowledge video about their topic at the commencement of the data collection process. According to diSessa (2008), “the central principle of conceptual change research is the constructivist idea that ‘old’ ideas (or mental structures) are influential in supporting or constraining learning (or development)” (p. 35). According to these prior knowledge videos, the students claimed to know nothing or very little about their topics. A more important theme arising from the prior knowledge videos was that the participants displayed an interest in their topic.

Initially, my rationale for the inclusion of the prior knowledge videos was to show how much each student had learnt. It became more important, however, to show how and why they developed their conceptual understanding along the way. As such, the prior knowledge videos were not as useful as many of the other data sources (such as the voice-over scripts) and are rarely referenced in the data analysis chapter.

Imagery files

Each child’s PowerPoint file was their digital workspace as all of their animation imagery was constructed within PowerPoint. This graphic imagery was constructed as a montage of auto shapes. I had instructed the children to construct relevant key frames (i.e., beginnings of movement sequences) before animating any actual movement. When viewed in the slide sorter view within PowerPoint, these key frames could then be easily dragged into a different position if necessary, to create the most appropriate sequence of events as a storyboard. Figure 3.2 is a screen shot of the slide sorter view within PowerPoint.
Figure 3.2. Screen shot of the slide sorter view in PowerPoint.

It was the appearance and functionality of the slide sorter view that gave me the idea of using “Storyboard” as the title for this thesis. The imagery within the PowerPoint files eventually made their way into the completed explanatory animations as the PowerPoint slides became animation source material by “Saving as” graphic files (.png format).

The graphic imagery was clearly more than a means of producing ‘visual building blocks’ for the animations. These images were tangible representations of each child's understanding of their conceptual topic that also provided a digital window into their thought processes. Although the participants were generating their imagery on computers, they were nonetheless, drawing. “Drawing involves more than simply forming images; it is equated with the capacity to think and feel” (Wright, 2011, p. 159).

The PowerPoint files were saved each week using a date suffix after the topic name (e.g., satellites 080911.pptx). The date suffixes were very important as they provided a chronology of the child’s work from one week to the next. This resulted in multiple files for each child and also provided an additional benefit of backing up the children’s work. The date suffixes were created using the convention of DDMMYY. (File extensions were either .ppt or .pptx depending on which version of Microsoft PowerPoint was on each child’s computer).

The digital domain allowed the children to literally undo their changes to facilitate trial and error. The basic functionality of saving as (a date-based suffix) was at the heart of
this method, as every new tangent became a new file. This was particularly useful in case mistakes needed to be undone. The issue of mistakes has interesting parallels here with Art and how we shouldn’t be too quick to correct or remove error. Discarded ideas are not without merit, as noted by visual artist Patricia Mullins (2009):

> When something doesn't work out, I take another sheet and do it again. If I were to rub out or destroy what went wrong I'd lose a sense of progression, or maybe later it might not look so bad (p. 49).

The PowerPoint files also contained a separate slide that functioned as a dumping ground for instances where I introduced new terminology. I did this as an attempt to reduce cognitive load for the children as new information could be dumped and reviewed at a later date. These non-graphic slides were simply omitted from the video-editing environment (i.e., imported but not selected) during the final stage of creating the animation artefacts.

**Voice-over scripts**

The voice-over script was a separate slide within the PowerPoint file of each student. As such it could be seen at various stages of development before it was eventually recorded as narration. The children were instructed to be careful that the content in these voice-over scripts was accurate and to only include information that they were confident about. The children were also made aware of the need to pass through two stage-gates (Cooper, 1990). Stage-gates are predefined steps that must be completed before progressing from one stage to another, namely:

1. The voice-over script had to be recorded before entering into the video-editing domain.
2. The imagery had to be synchronised with the voice-over script as the final stage of the explanatory animation creation process.

The children were generally more interested in working on their imagery than their voice-over script. Ironically, working on their voice-over script was the most direct method of finishing their animations because, until the voice-over script was completed and recorded, no imagery was rendered (i.e., extracted from the PowerPoint file by “Saving as” .PNG and then imported and assembled in video editing software).
The final voice-over scripts explained the content of each animation and were primarily descriptive in nature. Up until the final stage of the project, the voice-over scripts were also prescriptive as each sentence required corresponding imagery. Vygotsky (1978) has noted how the relationship between language and activity can be both descriptive and prescriptive at various times:

> Initially speech follows actions, is provoked by and dominated by activity. At a later stage, however, when speech is moved to the starting point of an activity, a new relationship between word and action emerges. Now speech guides, determines, and dominates the course of action; the planning function of speech comes into being in addition to the already existing function of language to reflect the external world (p. 28 original emphasis).

Zoss (2010) has noted how Vygotsky’s work on sense and articulation in relation to provisional texts continues to inform research on conceptual development. The children’s voice-over scripts were also provisional texts because they evolved throughout the project. Smagorinsky (2001) is insightful here about the dual role of provisional texts created by students. He argued that provisional texts simultaneously function as indicators of a child’s conceptual understanding and as a mediator for ongoing development of that concept. As such, provisional texts can function as cognitive tools in the explanatory animation creation task. These voice-over scripts became key data sources and had a direct influence on the completed explanatory animation and director’s commentary.

**Completed explanatory animations**

The completed explanatory animations were the focal point of the animation task and they also brought most of the children’s understandings together in the one artefact or product. A premise and theme throughout the current study is that the process of explanatory animation creation is more important than the product. This premise, however, must be balanced with the fact that the children’s motivation to participate in this project was based around the goal of creating a finished explanatory animation. It is unlikely that the same level of participation and enthusiasm would have been achieved without this goal and it also would have stopped the project from being an authentic task. That said, most of the learning was evident in the unrendered animations (i.e., the storyboards), which was actually a finding from the 2010 Storyboard pilot study. Hence, the completed explanatory animations in the current
study were not designed to embody the learning but, rather, provide the motivating goal and context for the learning task.

These explanatory animation products were also representations of the children’s cumulative learning. Prain and Tytler (2013) have noted that representations require further clarification. “Representations are always partial, selective, value-laden, perspectival, and offer abstracted, always constrained accounts of their referents. Learners need to know how to invest them with meaning” (p. 14). The investment of meaning in the completed animations was further enhanced through the addition of directors’ commentaries.

**Directors’ commentaries**

The concept of a director’s commentary is well known through entertainment contexts where a director records a commentary as an audio option on a DVD. This mirrors the same basic utility that was adopted for the current study where an additional, alternate audio track is merged with the primary video artefact (i.e., completed explanatory animation).

The directors’ commentaries provided another opportunity and context for student reflection. A premise for the current study gleaned from the 2010 Storyboard pilot study is that, on its own, a director’s commentary is insufficient to surface all of the issues and crossroads which the children encountered along their conceptual journeys. Hence, extracts from the directors’ commentaries appear in the students’ portraits wherever they are relevant.

More will be said about the genre of the director’s commentary in Chapter 5 because a survey of the literature would suggest that this is a new genre of research data that is unique to the current study.

**Student weekly reflections**

Each child made an audio recording as a weekly reflection about his or her animation progress. These recordings were always made towards the end of each session and the whole process usually took around fifteen out of our sixty minutes together. The
student reflections were transferred from my handheld audio recorder to my computer and then edited, mastered and transcribed.

Recording the weekly student reflections also served an important, relational purpose by demonstrating my genuine curiosity about each child’s progress. Paley (2007) has noted the positive effects that this interest has on children:

> When we are curious about a child’s words and our responses to those words, the child feels respected. The child *is* respected. “What are these ideas I have that are so interesting to the teacher? I must be somebody with good ideas”. Children who know others are listening may begin to listen to themselves, and if the teacher acts as the tape recorder, they may one day become their own critics (p. 157 original emphasis).

Although the students dictated the weekly student reflections, these reflections arose from discussions with me immediately prior to making the recording. I would always ask; “Who is ready to record?” and then proceed accordingly as it proved to be more efficient to work with the children who were ready to share their thoughts and ideas. Whenever children weren’t sure what to say, I could easily prompt them to remember the significant events from that session, as I was intimately involved in their progress.

**Attendance roll**

As the case study sessions were held after lunch each Thursday between 2:30 and 3:30 pm, the eight children who participated in the project usually went to their usual classroom first so that their grade teacher was aware that they still present at school. All grade teachers are required to mark their attendance roles in the morning and afternoon but I chose to maintain my own attendance record as this provided a quick snapshot of attendance (see Appendix D). I also recorded additional details for myself about absences by describing them as “A” (unexplained), “H” (family holiday) and “C” (school camp). These extra details helped me to gauge student engagement as some children (e.g., Magnus and Ryan) could still be described as having a perfect attendance record as they only missed sessions for reasons beyond their control.

By the end of this project there were thousands of date-based digital files, so the attendance role was also very useful in terms of data management, as I could quickly check which files would not be extant. For example, there are no “Stadium design” files between September 22nd and November 3rd as Ryan was on holiday throughout October.
Lesson plans

The majority of the animation sessions consisted of giving the students as much time as possible to work on their projects. This stemmed from my constructionist ideal “to produce the most learning for the least teaching” (Papert, 1993, p. 139). The initial focus sessions from me were responsive to the needs of the children as they arose, so a basic dot-point description of these sessions outlined the actual session development. The lessons plans were conceptualised as another way to track the progress of the project. All of the sixteen lesson plans are appended to this thesis as Appendix E.

Researcher reflections in weekly reviews

My researcher reflections were made on a weekly basis throughout the data collection phase and were readily shared with the children during our regular interactions. These researcher reflections were also my initial form of data analysis. This was the most difficult task because my comments usually concluded by identifying issues that the children might need to explore. My main task was to formulate suitable questions or suggestions to keep the children focussed. I was usually able to pose suitable questions or make relevant suggestions during my classroom interactions with the children, much like a teacher would in a normal classroom situation as “once ideas have been stated, both child and teacher can develop experiences that help the child think about a question” (Gallas, 1995, p. 29).

Sometimes I would pose a suitable question without knowing the answer myself. In these cases I had to investigate any specific content issues related to the children’s topics. The children were encouraged to do their own research, but in instances where I wasn’t able to assist them through my general prior knowledge, my own curiosity led me to conduct additional research on specific issues.

The Researcher reflections in weekly reviews were comments related to particular students in each instance. They had an immediate tone to them as they were primarily about week-to-week guidance. The Researcher’s reflexive journal, by comparison, also contained specific reflections about particular children, but the journal was focused more generally on any issues that might apply to the whole project.
Researcher’s reflexive journal

My journal entries were made on a daily basis between June 2011 and October 2012, focussing on interesting developments with various students, or additional insights that I was exploring. Although this started as a Reflective journal, I now refer to it as a Reflexive journal. Darling (1998) has articulated the differences as follows:

Although reflection influenced the development of reflexive practice, there are profound differences. Reflexivity is proactive as its focus is on providing practitioners with a tool that will simultaneously improve their communication and help make them [be] aware of assumptions and priorities that shape their interaction with others (para. 6).

My reflexive journal was a source of data but it also contained instances of preliminary data analysis. Altrichter and Holly (2005) have noted how research diaries can include data, interpretation, commentaries and reflection. This promotes ongoing analysis, as “preliminary results of analysis can indicate which additional data are necessary to fill in the gaps in a theoretical framework and to evaluate intermediate results” (ibid, p. 25). This is also in keeping with the nature of action research, where incremental improvements and refinements are made along the way.

Because the reflexive journal provided the most extensive and longitudinal record of analysis, it functioned as a backbone for my evolving understanding of the project, which was useful to cross-reference any of the other data sources. There are over 40,000 words in this journal so only the most relevant parts have been extracted and included in the body of this thesis (see Chapter 4).

Conceptual consolidation rubrics

My use of the conceptual consolidation rubric was initially conceptualised to assist me in the weekly, retrospective process of looking back at each child’s work to find key instances of conceptual change. The true significance of the rubrics, however, only appeared towards the end of the project when I noted a pattern that was consistently evidenced in each of the children’s work. This pattern is discussed further in Chapter 6.

The conceptual consolidation rubrics are in a table format, like a conventional rubric. The shaded boxes in each conceptual consolidation rubric records my weekly
assessments on the progress of each of the participants. Table 3.2 is an example of this rubric.

Table 3.2

*Conceptual consolidation rubric*

<table>
<thead>
<tr>
<th>Uses correct terminology</th>
<th>With assistance</th>
<th>Simplified terminology</th>
<th>Some correct terminology</th>
<th>Actual terminology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identifies relevant variables</td>
<td>Not apparent</td>
<td>With assistance</td>
<td>Basic understanding</td>
<td>Deep understanding</td>
</tr>
<tr>
<td>Identifies relationships between variables</td>
<td>Not apparent</td>
<td>With assistance</td>
<td>Basic understanding</td>
<td>Deep understanding</td>
</tr>
<tr>
<td>Self-assessment scale (1-10). Does the student think that they understand their topic?</td>
<td>1 2 3 4 5 6 7 8 9 10</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The final row contains each student’s self-assessment. According to Wilson and Johnson (2000), “the process of reflection is valued more highly by students if their reflections, such as their self-assessments, are included as part of the assessment process” (p. 19). In each instance, I made the actual shadings myself after each session. I didn’t ask the children each week what they thought their self-assessment should be as this was evidenced by the overall progress of their work and their weekly Student weekly reflections. The self-assessment scale in the bottom row was originally on a four-point scale of “No”, “Not really”, “Basic understanding” and “Yes”. All of the rubrics located in each child’s Weekly review use this four-point scale. During the Debriefing sessions, Magnus suggested that the self-assessment should be a 10-point scale, as he believed that the previous scale was too narrow. The final conceptual consolidation rubrics included in the children’s portraits in Chapter 4 now have the new 10-point scale.
Debriefing sessions

According to Lincoln and Guba (1985), a basic assumption for conducting a debriefing session is that the person conducting it is not the primary researcher but, rather, a “non-involved professional peer” (p. 283). Common reasons for holding a debriefing session are to gain a different perspective on a study and to give the participants a chance to interact with another person with the assumption that the participants can speak more openly and without prejudice. However, I was the only researcher at the debriefing session for the current study as I had additional objectives such as recording the directors’ commentaries and it also provided a chance for me to thank the children for their participation.

Although I had some questions that I had prepared for the session, the debriefing session was conducted in a semi-formal fashion, where the children were also free to take the discussion in different directions. Only six out of the eight participants were at the debriefing session so I organised a second session for the following week. The two debriefing sessions generated interview-like data as videos and subsequent transcriptions. The edited video footage from both sessions was twenty-one minutes long. To make this video easier to stream, I divided it into four chronological chapters. This resulted in six children featured in ‘Sessions 1A, 1B and 1C’ and the remaining two children featured in ‘Session 2’.

Transcriptions of relevant exchanges and discussions from these debriefing sessions have been embedded into the children’s portraits wherever they are relevant.

Organisation of the twelve data sources

There were thousands of files generated throughout this project, as there were eight children and twelve data sources over seventeen weeks of data collection. More comment is therefore required about the organisation of these data:

• All relevant data are included in a portrait of each child in Chapter 4. The extracts from all twelve data sources in the children’s portraits are provided to document each child’s conceptual journey.
• A table listing the location of all twelve data sources is included as Appendix F.
All of the twelve data sources originated as digital artefacts, and as such, these data are available on the Storyboard web site\(^1\). These data can also be accessed on a CD-ROM of the Storyboard website (Appendix A). Much of the data is only accessible in electronic form (such as the PowerPoint files), but all essential data\(^2\) have been included in the children’s portraits.

The Storyboard web site contains three sections as follows:

1. Videos and transcripts for the Prior knowledge videos, completed Explanatory animations and Directors’ commentaries.
2. A weekly review of each of the eight participants. These weekly reviews contain the Student reflections, Voice-over scripts, Researcher reflections, Conceptual consolidation rubrics and links to the PowerPoint files.
3. Digital appendices that provides links to the Researcher’s reflexive journal and the Debriefing sessions.

There is some deliberate overlap with the transcripts of video files as these transcripts are provided in the opening tables of each child’s portrait and also in the first row of the Storyboard web site as shown in Figure 3.3:

![Venn diagram of the thesis sections](image)

**Figure 3.3.** Venn diagram of the thesis sections.

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\(^1\) www.brendanpauljacobs.com

\(^2\) The thousands of decisions that I needed to make as to what constitutes essential data were mitigated by the inclusion of all data, even raw data, on the Storyboard web site (i.e., www.brendanpauljacobs.com) and/or CD-ROM (Appendix A).
The reason for including these transcripts in the body of this thesis is for the convenience of the reader. Of course, the videos can only be watched from the web site.¹

Figure 3.4 is a screen shot from the web site as an example of where to find the link to the videos and transcripts for Neil’s videos about satellites:

![Figure 3.4. Screen shot of a video link from the web site.](image)

The other important sections accessible from the web page are the weekly reviews² of each child. These weekly reviews contain five out of the twelve data sources as follows:

1. Student reflections
2. Voice-over scripts
3. Imagery files (i.e., PowerPoint files)
4. Researcher reflections in weekly reviews
5. Conceptual consolidation rubrics

¹ It would be logical to watch the animations from the web site when you first encounter the transcript tables in the children’s portraits so that you have a first-hand experience of the final video artefacts.

² Although the voice-over scripts, researcher reflections in weekly reviews and conceptual consolidation rubrics were constructed using written text, it would not be practical to format these texts into a hard copy format as the original table format allows the viewer to scroll across and down to cross-reference this text as a chronology of development for each child’s storyboard.
Figure 3.5 is a screen shot from the web site as an example of where to find the link to the weekly review containing all of Neil’s data about satellites:

Figure 3.5. Screen shot of a weekly review link from the web site.

The links to the children’s PowerPoint files from the weekly review pages enhanced the confirmability of the current study. Other issues concerning the integrity of this research will now be addressed.

**Integrity of the research methodology**

The integrity of qualitative research requires that researchers articulate and justify their assumptions and methods. Janesick (2000) however, questions the “psychometric assumption that the trinity of validity, generalizability, and reliability, all terms from the quantitative paradigm, are to be adhered to in research” (p. 391). Guba and Lincoln’s (1999) widely influential criteria of dependability, confirmability, credibility and transferability would seem to be appropriate categories for this discussion due to their close alignment with qualitative practices and dynamics. Guba and Lincoln (1999) were also careful to point out that the main reason for using any methodology is the “fit” (p. 141) between the axioms or propositions of the research and the phenomena under study.

Naturalistic enquiry accommodates emergence within a research design in contrast to rationalistic enquiry where the methods are usually predetermined. As such, the evolving and emergent nature of the current study provided a close fit for naturalistic enquiry as follows:
Issues concerning dependability

Dependability has some correlation to how well a study can be replicated. Dependability itself, however, is more about the extent to which a researcher can account for the changing context during case studies. In the current study I documented the context in three ways:

1. Through the *Researcher reflections in weekly reviews* that are included as a separate column in each participant’s *Weekly review* page in the data collection.
2. Through the weekly *Lesson plans* that include both the objectives for each session and a retrospective reflection about how these objectives were realised or changed.
3. Through daily entries in my *Reflexive journal*.

My use of a reflexive journal was in keeping with the aims and objectives of action research. Action research is known for effecting change and often this change occurs in the thoughts and revised plans of the researcher. According to Anderson, Herr and Nihlen (2007), “unearthing the tacit knowledge we bring to a question can be an important source of data, but it also needs to be critically examined” (p. 130). Guba and Lincoln (1999) have noted that naturalistic researchers often try to “recast their tacit knowledge into propositional form as soon as possible” (p. 145). As propositional knowledge is simply knowledge that can be stated in language form, the daily writing habit fostered by keeping a reflexive journal was an important and practical way to achieve this.

Issues concerning confirmability

Confirmability is often addressed directly after dependability as both issues deal with certification but in different areas of a study. “Confirmability shifts the emphasis from the certifiability of the enquirer to the confirmability of the data” (Guba & Lincoln, 1999, p. 147). The current study has augmented the ability of other researchers to confirm the data through the inclusion of all raw source data as hypertext links within the first column of the *Weekly review* page of each child. As such, these files don’t occupy any physical space, as the links are merely access options that are then left to the discretion of the reader. This enhanced level of referential adequacy is an affordance of presenting these data in the digital domain.
Although somewhat mechanical, the chronological file-naming conventions used throughout the current study also enhanced confirmability. This practice also demonstrated methodological congruence through the creation of a logical, chronological framework for the data trail.

**Issues concerning transferability**

Transferability relates to the possible extent that elements from a study might reasonably be transferred to other settings. Guba and Lincoln (1999) proposed that researchers provide a detailed and sufficiently thick description to the extent that others might be afforded a “vicarious experience of it” (p. 148). The purpose of the vicarious experience is to enable others to make judgments about a study, particularly about the researcher’s working hypotheses, which might be transferable to another context. Lincoln and Guba (1985) describe transferability in relation to a transfer between the *sending* and *receiving* contexts and further note that “transferability inferences cannot be made by an investigator who knows only the sending context” (p. 297 original emphasis). Establishing the feasibility for transferability then becomes the responsibility of the researcher in the receiving context as “the burden of proof lies less with the original investigator than with the person seeking to make an application elsewhere” (ibid, p. 298).

**Issues concerning credibility**

Credibility and trustworthiness are basically synonymous, as the key requirement appears to be a critical perspective. According to Sullivan (2006), the challenge for the researcher is to “maintain and monitor a creative and critical perspective so as to be able to document and defend the trustworthiness of interpretations made” (p. 29).

Credibility is also about the extent to which the participants in a study would agree with the researcher’s findings. Lincoln and Guba (1985) have said that the researcher’s interpretations must be “credible to the constructors of the original multiple realities” (p. 296 original emphasis). I attempted to understand these multiple realities through the personalised comments that I made about each child through my *Researcher reflections* in the *Weekly reviews*. This unfolding chronology was done to reduce the margin of error from my interpretations. The dialectic nature of these interactions and
the importance attached to the children’s reflections were an attempt to foster the co-
construction of knowledge. The fact that I had also known all of the children for many
years and that the study itself ran for a whole-semester were examples of prolonged
engagement as credibility was something that we could build on rather than establish
in the first instance. According to Lincoln and Guba (1985), “it seems likely that unless
the inquirer began as an accepted member of the group or agency being studied,
distortions can never be overcome” (p. 302).

Another important component of credibility is the triangulation of data. In order to
improve the reliability of data, triangulation is a general principle in which multiple
sources of data are presumed to be better than single sources. Triangulation is not
just the collection of multiple data sources, but also the application of multiple
perspectives for analysing it. A more recent metaphor for validating or conceptualising
data is that of a crystal (Richardson & St Pierre, 2008) where “what we see depends on
our angle of repose - not triangulation but rather crystallization” (p. 478).

Summary

I would like to summarise this chapter by using some of the elements of filmmaking as
an allegorical metaphor for the research methodology and analytical framework
developed for the current study. The following filmmaking metaphor was inspired by
Clarke (2008) who noted that for the qualitative researcher, data isn’t simply collected
(as if it is scattered on the ground, waiting to be scooped up), but rather, composed
and captured like a filmmaker who consciously and deliberately points a camera as a
generative process, knowing where to look.

Constructionism is like the title of a film. The title is supposed to embody what the film
is about, but is often a mere starting point as no single word or phrase can truly capture
the entirety of a film. Likewise, constructionism provided a rationale for making
artefacts but is insufficient to tell the rest of the story.

Action research is like the genre of the film as a broad category for this research, with
practitioner action research further defining some of the practices involved. Naturalistic
inquiry could also be likened to genre for similar reasons.

The dual stimulation method can be likened to the role of a location manager who
decides when and where to shoot the film. In this sense, the dual stimulation method,
although broad in terms of possibilities, became highly specific once the explanatory
animation creation task was established.

The case study as a research method is like the role of a casting agent who enlists
people to participate in a film through their direct involvement. Each of the eight
children in the current study constituted a separate case and yet these eight cases
were subsequently combined like scenes in a film.

CHAT is like the behind-the-scenes work of the film editor, seemingly invisible and
technical yet having the ability to completely transform the final product throughout
each stage of the process. As an umbrella methodology, CHAT is sufficiently inclusive
as a way to conceptualise every part of this research, especially when used as an
application of the ZPD.

The director was each of the eight children, and my role was like that of an executive
producer. The final component in this metaphor is the script, although there was no
actual script as each of the children started their animation with little or no prior
knowledge. The children’s voice-over scripts soon appeared and continued to evolve
throughout the project. The evolution of these voice-over scripts was a major
component of the portraits that were used to detail the children’s progress in Chapter 4
as data analysis and results.
Chapter 4. Data analysis and results

In qualitative research the facts never speak for themselves (Eisner, 1998, p. 39).

Introduction to the data analysis and results

The current study sought to discover how the explanatory animation creation task might surface and document conceptual crossroads. These conceptual crossroads were signposted according to the issues pertaining to each child’s chosen topic. In other words, it is only in direct reference to these topics that any sense can be made of conceptual change in relation to any particular child.

The final analysis of each child takes the form of a portrait where I draw on all relevant data sources to identify instances of conceptual change for each child. To identify and analyse these conceptual changes, I chose to compare and contrast two of the twelve data sources:

1. The children’s voice-over scripts
2. My researcher reflections (in weekly reviews) about the same topics

Focussing the analysis on these two sources affirmed that the children’s voice-over script was the most important data source which the child generated as this formed the essence of their explanation. Similarly, the researcher reflections were the most important data source which I generated as these contained my historically bounded (i.e., written in 2011) instances of data analysis. The other data sources that each child generated also informed these portraits as evidenced through various instances of reinforcement or contradiction. In other words, the analysis is primarily between what each child knew and what I knew. These two items then constitute the ZPD quite logically as an analysis within the ZPD.

Creating zones of proximal development

The ZPD is usually understood as a context for teaching and learning rather than a framework for analysis but this approach is not without precedent. Sutter (2001) has noted the strong connection between the ZPD and Vygotsky and Sakharov’s dual stimulation method:
The concept of the zone of proximal development goes together with the concept of the method of double stimulation. That means that when your analysis focuses on ZPD, the relation between people is highlighted, and the instrument and sign used in the interaction are put into the background. But of course they are there, because people influence each other through artifact mediation, and through the method of double stimulation. In the second case, when your account focuses on the method of double stimulation, the instruments and the signs are in the forefront, and the interactions between people are in the background. But each time, the ZPD and the method of double stimulation go together. They are, as I see it, twin concepts in Vygotsky’s cultural-historical psychology (p. 18 original emphasis).

The ZPD provides the frame of reference that identifies what each party understands about the topic. Changing the topic changes the frame of reference so this further affirms the important point that each child’s topic constitutes a different case for analysis. The grounds for comparison (i.e., why contrast the children’s voice-over scripts and my researcher reflections?), involves the notion that storyboards are semiotic tools for cross-modal cognition. The co-construction of knowledge as evidenced through the evolving digital artefacts also surfaces the researcher’s understanding of the topic. This provides a logical context for analysis as I would not be able to make any judgements about each child’s work without reference to my own understanding (Leite, Mendoza & Borsese, 2007).

Diagrammatically, it is common to represent the ZPD using irregular shapes to acknowledge that learning is often a messy phenomenon, quite different from the neat boundaries implied by some Venn diagrams. The point of reconceptualising the ZPD as Figure 4.1 with the red extensions is to allow for instances where the child’s knowledge exceeds the helper’s knowledge.

![Figure 4.1. Overlap within Vygotsky’s Zone of Proximal Development.](image)
In the current study, to enter into the process of conceptual consolidation it was important for me, as the researcher, to grapple with the same conceptual issues as each of the participants. As each participant was free to choose their own topic, this put me in an interesting position because these topics were not necessarily areas in which I claimed to have any expertise. This caused me to reflect on the abstract-concrete continuum that was discussed in the literature review. As the ZPD is so widely accepted, it seems that the ZPD should also be able to account for the way in which new knowledge is acquired, particularly how new knowledge might not be instantly consolidated within the mind of the learner. This new perspective led me to reconceptualise a revised diagram for the ZPD as depicted in Figure 4.2.

![Figure 4.2](image)

**Figure 4.2.** Concretising new knowledge in the ZPD.

The dotted line for the outer shapes, for both the child and the helper, represent abstract knowledge that is known but not fully understood. The solid lines of the inner shapes indicate where conceptual consolidation has occurred. All of the shapes have been simplified compared to Figure 4.1 to improve the clarity of the diagram (now that there are four shapes instead of two) but the notion of the child’s knowledge exceeding the helper’s knowledge is still retained.¹

¹ I also contemplated an extension of this metaphor where the quadrilateral shapes are viewed as people engaged in the act of rock climbing where each point (i.e., limb) moves towards the unknown and is then stabilised as a new spike is secured to the rock.
Portraits of the children’s conceptual journeys

The children’s portraits have been designed and presented using the following format and order:

- **A video transcript table** consisting of screen shots from each child’s three video artefacts along with the transcription of each video. The three videos are the prior knowledge video, completed explanatory animation and the director’s commentary.
- A short **introduction** of each child and their chosen topic.
- A **ZPD** discussion detailing which element of the explanatory animation creation task was most conducive in creating the ZPD for each child.
- A narrative detailing the **conceptual journey** of each child. These narratives are often chronological due to the evolving nature of the children’s understanding. Each of these sections concludes with the final conceptual consolidation rubric for each child.
- An abridged **summary table** of each child’s work serves to summarise each child’s conceptual journey in relation to each child’s content knowledge and a restatement of any issues or obstacles pertaining to each child during the project. “Issues or obstacles” is a heading in each of these tables as the animation task invariably involved conceptual problem solving. These problems usually related to either the suitability of the chosen metaphor or a re-evaluation of the scope of each topic.

Throughout this chapter, my voice as the researcher is present in two distinct ways. Interestingly, the contrast is not between my teacher and researcher roles, as the children displayed no such dichotomy in their interactions with me. Rather, the two voices are:

a) **Me as the researcher** making historically bounded comments and reflections from one week to the next in the second Semester of 2011. This was a natural component of the action research process being “integral with reflection during data collection” (Noffke & Somekh, 2005, p. 91). These instances have been referenced according to their source as Researcher reflections in weekly reviews, daily Researcher’s reflexive journal entries or retrospective reflections from the weekly Lesson plans.

b) **Me as the current voice** completing this analysis in 2014 (all comments within this chapter are me as the 2014 voice except where noted).
The following eight portraits are not in alphabetical order. They have been rearranged into the most appropriate order to document and illustrate the issues that arose during the case study.
A portrait of Harriet

Harriet was a Grade 6 girl who chose to investigate the question of “How does hair grow?” Table 4.1 contains the transcripts of Harriet’s three videos.

Table 4.1

Harriet’s video transcripts for “How does hair grow?”

<table>
<thead>
<tr>
<th>Table</th>
<th>Transcript</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior knowledge video</td>
<td>My topic is how hair grows and I don’t really know much about it except that it’s from your skull and there’s a tiny stem inside your skull and it grows from there.</td>
</tr>
</tbody>
</table>
| Completed explanatory animation | “Is hair dead or alive?” A lot of people ask that but the truth is…hair is dead and that’s why it doesn’t hurt when you cut it. But the reason it does hurt when you pull it is because you’re also pulling the stem and that’s where the hair grows from. There are many different components that make up the hair.  
  • the skin around the skull which is also known as the scalp  
  • the hair string  
  • the sebaceous glands  
  • the dermal papillae and  
  • the hair shaft.  
So the hair grows on and on so slowly that you don’t even notice it. It grows and falls out at the same time but because it grows so fast, people can choose to have long hair.  
Now the reason that people have different coloured hair and different types of hair like curly, straight or wavy is because of a little something called…genes. |
| Director’s commentary | The reason I chose this topic is because I’m interested in how hair grows and I’ve always seen these ads about hair animations and they look sort of fun and interesting and I’ve always sort of wondered [about] that.  
Brendan asked me questions to keep me learning and I added that in my animation. I liked the way how the labels worked. I think it makes more sense when you have labels and just to show where they are and where it is. That’s why I put it there. The lines, when they fall out I thought was a good animation too.  
Genes was my answer to different colours and curly, straight and wavy but I didn’t really get into any of the details because that’s not my topic. |
Introducing Harriet and her topic

Harriet’s rationale for her choice of topic was stated in her director’s commentary about being “interested in how hair grows”. In retrospect, the cyclical nature of Harriet’s topic escaped both Harriet and myself. This issue will be revisited after discussing Harriet’s experiences within the ZPD.

Creating the ZPD with Harriet

Harriet was the most independent child out of all of the eight participants. She noted in her director’s commentary that I asked her questions to keep her learning. These questions helped create the ZPD for Harriet as she begun to seek more detail about the structure of hair. One of my suggestions was that Harriet should create some cross-sectional imagery. Figure 4.3 is a screen shot from a labelling sequence where various components of the scalp and hair shaft were introduced.

Harriet had encountered some information that I had never heard of such as “sebaceous glands”. She appeared to be engaged and eager to research new terminology. As such, Harriet essentially directed her own progress. I was grateful for Harriet’s self-motivation, as there was always at least one of the other children with their hand up, wanting help.
Harriet's conceptual journey

In many ways Harriet was the model student as she was diligent, focussed, engaged and making steady progress. She only sought my assistance for technical animation advice rather than specific content knowledge. Figure 4.4 is an example of how we applied the attributes of various hair types to the text itself as a creative way to augment meaning through the enhanced use of on-screen text.

![Curly Straight Wavy GENES!!!](image)

*Figure 4.4. Concluding screen shot from “How does hair grow?” animation.*

Harriet was wise to have noted the limitations of her topic by including the word “genes” without attempting any explanation:

> Genes was my answer to different colours and curly, straight and wavy but I didn’t really get into any of the details because that’s not my topic (“How does hair grow?” director’s commentary).

I have continued to reflect on Harriet’s work over the past few years. My most recent reflection is that the topic that Harriet presented could have been more accurately described as “What is hair made of?” To further explore the system qualities of hair growth, we should have looked into the variables that affect the hair growth cycle. I soon learned that there are three distinct stages of the hair growth cycle which is significant because Harriet and I never encountered any of these terms during the project. The absence of this key information accounts for our failure to identify the system qualities of hair growth. These three stages could also be called phases as the Oxford English Dictionary defines a *phase* as “a particular stage in recurring sequence of movements or changes”. The three phases of hair growth are:
1. Anagen (active phase lasting between 2 - 6 years)
2. Catagen (transitional phase lasting around 2 weeks)
3. Telogen (resting phase lasting between 1 - 4 months)

Harriet’s portrait was unlike any of the other seven children as her animation could be characterised as an animated poster with annotated diagrams and corresponding narration, rather than an explanatory narrative. This is because Harriet’s voice-over script described elements rather than explaining relationships between them. My own understanding of Harriet’s topic and my assessment of her animation have changed dramatically since Harriet completed her work in 2011. Table 4.2 is Harriet’s conceptual consolidation rubric with my 2011 assessments shaded in grey and my updated, 2014 assessments shaded in orange.

Table 4.2
Harriet’s final conceptual consolidation rubric

<table>
<thead>
<tr>
<th>Uses correct terminology</th>
<th>With assistance</th>
<th>Simplified terminology</th>
<th>Some correct terminology</th>
<th>Actual terminology</th>
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<td>Basic understanding</td>
<td>Deep understanding</td>
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<td>Basic understanding</td>
<td>Deep understanding</td>
</tr>
<tr>
<td>Self-assessment scale. Does the student think that they understand their topic?</td>
<td>1 2 3 4 5 6 7 8 9 10</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The reason why my original assessments (in grey) were not higher is that Harriet didn't discuss any factors that influence hair growth or health. Harriet’s new orange shading in Table 4.2 indicates that she hadn’t identified these key phases as neither Harriet nor I had encountered any of these words during the construction of her animation. I’m confident that we would have discovered these phases if we had amended the title to be “The hair growth cycle”. Possible metaphors to generate discussion could have been grass growing, or finger nails growing. The hair growth cycle would have lent itself to animation as the duration of the anagen stage explains why some people can grow longer hair than other people.

The ZPD diagram presented at the start of this chapter as Figure 4.1 (with the overlapping red spikes where the child’s development surpasses the helper) was
inspired by my work with Harriet, particularly near the beginning of the project where she started using terminology that I had never heard of. I would have quickly discovered these terms if I had done any of my own research but this was the one case where a child did all of their own research. This further caused me to reflect on my role as a teacher working in a primary school. The old adage the squeaky wheel gets the grease is characteristic of the way that the most demanding children usually receive the most assistance from their teacher. In future I will seek to create opportunities to extend the learning of the competent, independent children with suitable questions and challenges. Harriet’s failure to identify the three phases of hair growth was really my own failure to ask her the right questions such as “What is the hair growth cycle?” A summary of Harriet’s conceptual journey is presented in Table 4.3.

Table 4.3
Summary of Harriet’s conceptual journey

<table>
<thead>
<tr>
<th>Harriet - Grade 6 girl</th>
<th>Prior knowledge</th>
<th>Issues or obstacles</th>
</tr>
</thead>
<tbody>
<tr>
<td>How does hair grow?</td>
<td>“My topic is how hair grows and I don’t really know much about it except that it’s from your skull and there’s a tiny stem inside your skull and it grows from there.”</td>
<td>There was no metaphor used in this animation. The animated diagram style of this animation was enhanced through the use of cross-sectional imagery.</td>
</tr>
</tbody>
</table>

**Choice of imagery**

<table>
<thead>
<tr>
<th>Enhanced use of text</th>
<th>Relevant variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hair texture and colour were attributes of hair rather than actual variables.</td>
<td></td>
</tr>
</tbody>
</table>

**Behind the scenes**

<table>
<thead>
<tr>
<th>Different perspectives</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>A different perspective on this animation has only become apparent now (i.e., 2 ½ years after the data collection). This different perspective would have led to a recommendation to change the topic itself.</td>
<td>If the topic had been changed to “The hair growth cycle”, then the three phases of growth (i.e., anagen, catagen and telogen) would have been identified. These three variables would have helped uncover the system qualities of hair growth as a cycle.</td>
</tr>
</tbody>
</table>

This animation challenged me to rethink my definition of a conceptual topic. The success of this animation could be measured by the extent to which the system qualities were identified. In this case, the system qualities were not identified as the variables were absent.
A portrait of Sunny

Sunny was a Grade 5 boy who initially chose to investigate “Solar panels”. Table 4.4 contains the transcripts of Sunny’s three videos.

Table 4.4

<table>
<thead>
<tr>
<th>Sunny’s video transcripts for “Solar cell efficiency”</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Prior knowledge video</strong></td>
</tr>
<tr>
<td>![Screen with video icon]</td>
</tr>
<tr>
<td><strong>Completed explanatory animation</strong></td>
</tr>
<tr>
<td>![Diagram of solar panels]</td>
</tr>
<tr>
<td>![Rainbow]</td>
</tr>
<tr>
<td><strong>Director’s commentary</strong></td>
</tr>
<tr>
<td>![Diagram with Band gap energy]</td>
</tr>
</tbody>
</table>

My topic was so complicated that, although it’s still the longest, we had to remove some of the information that we were going to include at the start.

85
Introducing Sunny and his topic

Sunny was one of the youngest participants in the current study but he was also very capable and articulate. As a researcher, this allowed me to focus on where he was going with his ideas rather than trying to interpret what he was saying.

Sunny had defined his topic as “Solar power” during our initial discussions leading up to the first session. During the first session, his topic changed to “Solar panels” to shift the focus onto how solar panels worked as the benefits of solar power were self-evident. Sunny’s prior knowledge video still had echoes of the solar power theme with his reference to saving money on electricity bills. Sunny eventually changed his topic to “Solar cell efficiency” towards the end of the project.

Creating the ZPD with Sunny

I found Sunny’s topic to be the most difficult out of the eight topics that the children chose to explore. My own understanding of the children’s eight topics was expanded throughout the project, but it was my collaboration with Sunny that was most characteristic of a “mutual zone of proximal development” (John-Steiner, 2000, p. 177) as I was learning alongside him throughout the full two terms.

Our conceptual journey together and the difficulties that we faced seemed related to specific content knowledge for the representation of electricity. Beaty (1995) noted that children are often presented with incorrect or simplistic information regarding electricity due to the inherent complexity of the topic and the perpetuated misconceptions held by many teachers in both primary and secondary school settings. Hence, guiding Sunny within the ZPD was particularly difficult for me, as I had reached the limits of my own understanding for this topic. I grappled with this situation and documented it in my reflexive journal:

---

1 I found it interesting that in Sunny’s director’s commentary, he described his decision to change topics as “halfway through” the project, however, the shift of topic actually occurred during session 15 which was 87.5% of the way through. Sunny’s concept of time (or at least his concept of time in relation to this project) was also skewed as Sunny thought that the whole Storyboard project ran for one term when it was actually two terms.
After today’s session I was further examining my role in this whole process, particularly with assisting the recording of the student reflections. Sometimes the children don’t know what to say because they’re not sure where their research is heading. This is part of the “you don’t know what you don’t know” dilemma. In such cases, I’m more like a coach where I provide encouragement and guidance. For some topics like "Solar panels" I am equally mystified (Researcher’s reflexive journal, 20th October 2011).

Perhaps the progress of Sunny’s project was also hindered by the fact that he missed two out of the sixteen Storyboard sessions. He would have missed four if I hadn’t arranged private make-up sessions with Sunny on two occasions so that we could finish the project. We discussed the dynamics of this during the debriefing session with the other students. Molly was correct in surmising that the class-of-one with Sunny was awkward. If ideas had been flowing between Sunny and me then it wouldn’t have seemed awkward. But because we both were completely stumped, our reflection turned into an overtly self-conscious pursuit:

**Brendan:** There was a session with "Solar cell efficiency" [Sunny] where it was just one person because he missed a few and it was just you and I [Sunny and Brendan]. That was almost a little strange, just one person [rather than the full group]. Not a little strange but it was…

**Molly:** [speculating] It was awkward.

**Sunny:** Didn’t we have two of those sessions?

**Brendan:** We had two of those sessions. Often I didn’t give you time to just think. I think it’s…a small group’s perfect ‘cause then I can give you attention and then leave you alone for a bit to, to think (Debriefing session 1C, 15th December 2011).

The ZPD that Sunny and I were in was clearly a mutual zone as we were both working at our outer limits of understanding, simultaneously. Towards the end of this session, I encouraged Sunny to continue looking into NP junctions. I also promised him that I would do likewise as it was clear to both of us that we couldn’t proceed any further without some insight here.

**Sunny’s conceptual journey**

Sunny and I had discussed animating the component parts of the NP junction and then explaining each part while it was constructed on the screen. Sunny articulated how he conceived this process in his reflection, saying, “I’m going to build [literally draw each
part from scratch by starting with a blank screen] the solar panel as I go through. So I’m going to start with one layer and then do the next one and so on” (Student reflection, 20th October 2011). Of course, Sunny had to create his imagery via this construction process anyway but he was saying that he wanted his finished animation to reflect this process. The pedagogical principle that we discussed was that of starting simple and progressively adding details. The inner workings of the NP junction, however, still alluded us. My reflection at that time was that we needed to go further into the nature of electricity at the component level:

The definitions that he [Sunny] encountered for "N type" and "P type" semiconductors were identical except for certain variables which were switched around. Interestingly, Sunny concluded that each type of panel was interchangeable when, in fact, they are complete opposites. This should be resolved soon when he looks into the structure and composition of the semiconductors (Researcher reflection, 27th October 2011).

A breakthrough finally occurred when I realised that the NP junction needed to be viewed as a whole unit rather than as component parts, an understanding that I worked on via my reflexive journal:

After more reading and research into solar panels, I think I’ve identified the stumbling block that was halting our progress. This insight is that an NP junction is easier to understand in context. Viewing the N (negative) and P (positive) plates in isolation was confusing as we were breaking the system down too far. The junction effect that creates the voltage is only functioning when the two plates are brought together into a junction. It’s almost like trying to understand human reproduction by analysing the properties of sperm and ova without investigating what happens when they combine (Researcher’s reflexive journal, 24th November 2011).

The potential to see this system perspective had been in front of us all along but we didn’t see it because we were too focused on the component parts. This new, integrated view of NP junctions led to a change in the actual topic:

Sunny changed his topic to "Solar cell efficiency" today in response to my suggestion that we narrow the scope to efficiency issues. This allows us to cover important and interesting issues around solar cells without getting stuck at the atomic level (Researcher reflection, 1st December 2011).

Figure 4.5 shows the typically dark colour of solar cells as being optimised to absorb light energy. The voltmeter on the right-hand side implies that electricity is being generated without having to address or explain the direction of the current.
Figure 4.5. Screen shot from “Solar cell efficiency” animation.

The most difficult issue to animate was band gap energy. Sunny defined band gap energy as “the strength of the voltage” (“Solar cell efficiency” animation) and noted that its magnitude “depends on how much energy is required for electrons to jump across the NP junction” (ibid). Figure 4.6 is a metaphorical visualisation of an NP junction where the phrase band gap energy was stretched to suggest a literal gap. The positive and negatively charged materials in a typical NP junction create a chemical gap and not a physical one, but the use of distance in this animation reinforced the notion of a gap to be crossed. Andreou (2013) calls this a graphical metaphor when words or symbols are “arranged in meaningful spatial configurations that metaphorically (or allegorically) express relations among the concepts [or] the objects” (p. 15).

Figure 4.6. A graphical metaphor of band gap energy as a physical gap.
Sunny also alluded to this graphical metaphor in his director's commentary:

In real life the band gap energy doesn't mean that the negative and positive sides are further apart (like it looks like in the animation) but that was a good way to show it so that people would understand (“Solar cell efficiency” director’s commentary).

Figure 4.7 extends the graphical metaphor by showing how sunlight can be wasted when the NP junction is not optimised to harness strong light.

![Figure 4.7](image)

**Figure 4.7.** Screen shot of wasted energy in an NP junction.

Sunny concluded his director’s commentary by stating that, “my topic was so complicated that, although it’s still the longest, we had to remove some of the information that we were going to include at the start” (“Solar cell efficiency” director’s commentary). The deleted scene that Sunny referred to would have accompanied the following narration:

Another issue is that the electricity generated by a photovoltaic cell needs to travel through a semiconductor and semiconductors aren’t great at conducting electricity. Wires are good conductors but they block out light so new transparent conductors are being developed to improve solar cell efficiency.

This scene was deleted to shorten the explanation and keep the duration under two minutes. We were quite serious about including this final point as it seemed that this extra information afforded a more complete explanation. However, we couldn't think of a clear way to represent this information graphically as the attributes of semiconductors, although relevant, were complex enough to have constituted a whole new topic.
Sunny realised that solar cells involved changes from one type of energy into another but he was initially mistaken when he identified heat as the original energy source rather than light. “I'm thinking that I need to find out how it changes from one type of energy, heat energy, into electricity that powers things” (Student reflection, 21st July 2011). When Sunny corrected this misunderstanding, he was able to discuss solar cells in terms of the reflective qualities of the outer layer of photovoltaic cells as an issue affecting solar cell efficiency.

After the last animation session, I was left with the task of completing any missing imagery as I had no further opportunities to work with Sunny. Sunny had given me instructions to animate ascending numbers from 0% up to 40% to accompany his voice-over script for, “Even the best solar cells only achieve around 40% efficiency”. After I had generated the number sequence, I decided change the order by starting at 100% and working down to 40%. I felt that 0, 1, 2…39, 40 focussed on how far we’ve come in terms of solar cell technology in contrast to 100, 99, 98…41, 40 which implies that we still have a long way to go. I attribute this subtle refinement to the fact that I had a further opportunity to reflect on the content. When I met with him Sunny during the debriefing session the following week he said that he approved of my choice for this scene.

Table 4.5 is Sunny's final conceptual consolidation rubric.

Table 4.5
Sunny’s final conceptual consolidation rubric

<table>
<thead>
<tr>
<th>Uses correct terminology</th>
<th>With assistance</th>
<th>Simplified terminology</th>
<th>Some correct terminology</th>
<th>Actual terminology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identifies relevant variables</td>
<td>Not apparent</td>
<td>With assistance</td>
<td>Basic understanding</td>
<td>Deep understanding</td>
</tr>
<tr>
<td>Identifies relationships between variables</td>
<td>Not apparent</td>
<td>With assistance</td>
<td>Basic understanding</td>
<td>Deep understanding</td>
</tr>
<tr>
<td>Self-assessment scale. Does the student think that they understand their topic?</td>
<td>1 2 3 4 5 6 7</td>
<td>8.5 9 10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4.5 shows Sunny as not achieving a “Deep understanding” of the topic but I wouldn't even give myself the “Deep understanding” rating due to the complexities of this topic.
A summary of Sunny’s conceptual journey is presented in Table 4.6.

**Table 4.6**  
**Summary of Sunny’s conceptual journey**

<table>
<thead>
<tr>
<th>Solar cell efficiency</th>
<th>Prior knowledge</th>
<th>Issues or obstacles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunny - Grade 5 boy</td>
<td>&quot;My topic is solar panels and what I know about them is that they take something from the Sun and make it into energy that can power stuff like, umm, and, it saves you money on electricity bills. And that’s most of the, no that’s all of the stuff I know about solar panels.”</td>
<td>“Solar power” was originally too broad as a topic as was “Solar panels”. Shifting the focus onto issues affecting “Solar cell efficiency” effectively simplified the topic.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Choice of metaphor</th>
<th>Implementation of metaphor</th>
<th>Relevant variables</th>
</tr>
</thead>
</table>
| ![Image](image1.png) | ![Image](image2.png) | • Sunlight  
• Photovoltaic cells  
• Current  
• Voltage  
• NP junctions as cohesive units  
• Band gap energy |

<table>
<thead>
<tr>
<th>Behind the scenes</th>
<th>Different perspectives</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunny initially wanted to show a completed solar panel and then explain the component parts using labels. Instead he decided to <em>build</em> the imagery and explain it along the way.</td>
<td>Our thinking had literally become polarised by focusing on Negative and Positive. This topic only made sense to us when we finally realised that the NP junction had to be viewed as a whole unit.</td>
<td>This topic challenged me the most in terms of my role as the more experienced helper within the ZPD. My own conceptual consolidation throughout the process of assisting this participant led me into <em>mutual zones of proximal development</em> (John-Steiner, 2000).</td>
</tr>
</tbody>
</table>
A portrait of Neil

Neil was a Grade 6 boy who chose to investigate “Satellites”. Table 4.7 contains the transcripts of Neil’s three videos.

Table 4.7

<table>
<thead>
<tr>
<th>Neil’s video transcripts for “Satellites”</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Prior knowledge video</strong></td>
</tr>
<tr>
<td>![Diagram]</td>
</tr>
<tr>
<td><strong>Completed explanatory animation</strong></td>
</tr>
<tr>
<td>![Diagram]</td>
</tr>
<tr>
<td><strong>Director’s commentary</strong></td>
</tr>
<tr>
<td>![Diagram]</td>
</tr>
</tbody>
</table>
Introducing Neil and his topic

Neil began his animation cautiously and often checked with me to see that he was doing the right thing:

Neil seemed to be very concerned that he complied with my guidelines as he often asked; "Can I do this?" I have since reassured Neil that he is free to follow his own path as it is his learning and decision-making processes in which I am most interested (Researcher reflection, 21st July 2011).

This cautious approach changed dramatically after the first session once Neil understood that he didn’t need my approval. The "head start" that Neil referred to in his director’s commentary was that he immediately grasped the concept of the iterative PowerPoint animation technique for "Insert duplicate slide". I had a constant struggle with Neil from this point forward to get him to complete a key frame before proceeding to create the movement sequences. Otherwise, Neil would end up double-handling all of his imagery as each correction or improvement would have to be implemented multiple times. This was an issue that ran right through until the final session and so this issue will be revisited during Neil’s summary.

Satellites seemed to be a great topic for an animation as the visual and spatial possibilities of showing the Earth as a globe appeared to be obvious. Neil commenced the project knowing that satellites are “used for transmitting signals to devices around us, say, for cable TV, or, umm, GPSs” (“Satellites” prior knowledge video). The next logical step for Neil was to move beyond what satellites do so that he could investigate how satellites work.

Creating the ZPD with Neil

As with many of the children in the study, asking the right questions was an important part of guiding their progress. The question that moved Neil into the ZPD was, “How many satellites are needed to transmit a signal around the world?” (Lesson plans, 8th September 2011). My reason for posing this question to Neil was that I wanted him to understand that satellite signals travel in straight lines. The octagon shape in Figure 4.8 is a metaphor for the Earth.
Figure 4.8 implies that eight satellites are required for a global transmission due to the eight sides of the octagon shape. The noted science fiction author Arthur C. Clarke answered his own hypothetical question about this issue in 1945 [several years before satellites were even invented] stating that “three satellite stations would ensure complete coverage of the globe” (p. 306). Neil’s use of the octagon metaphor was to illustrate the statement that “satellites can only send transmissions in straight lines but the Earth is round” (“Satellites” animation). An octagon looks more like a globe than a triangle, which places this metaphor on the realistic side of Pratt and Garton’s (1993) scale of arbitrariness continuum, as the geometric issue closely resembled the phenomenon being represented. It was logical to proceed from the octagon metaphor to the planetary, Earth imagery as shown in Figure 4.9.

Figure 4.9. Screen shot of a satellite signal.

Animating the satellite transmission lines smoothly proved to be impractical in PowerPoint because it wasn’t possible to make small, incremental changes between
each frame. Any disruption to the position of the lines was unacceptable so we got around this by drawing a completed transmission signal (i.e., red line) and then erasing small parts of the line in Adobe Photoshop. Each change was then “Saved as” a new file and then these files were played in reverse order to show the transmission signal moving and expanding. Although Figure 4.9 was an actual screen shot, it also provided the source material for all of the preceding animation frames using this reverse-engineering approach.

**Neil’s conceptual journey**

Neil began a tangent about satellite protocols during Session 8:

So today I did a bit of research and I found out that a satellite, say one company’s satellite, can’t send a transmission to a different company’s satellite ‘cause they need to have, umm, the same program (or something like that) to get it to where it needs to go. I’m going to make a, some more slides that, I’m going to put in a new coloured satellite. And I’m going to have one of my satellites send a signal to it and then it comes up with a red cross on the new satellite and it sends it back (Student reflection, 22nd September 2011).

I encouraged Neil to abandon this issue because I considered this to be additional information that would make his animation too long. I likened the compatibility issue to different cell phones using different networks and how the differences “probably relate to settings, configurations and company or country protocols rather than true functionality” (Researcher reflection, 22nd September 2011). Neil agreed to abandon the compatibility issue but this discussion proved to be useful to help determine what is essential information for this topic.

Having described and depicted the satellite transmission signal path, the final issue to be covered related to what actually happens when a signal is received and then transmitted to another satellite. Neil addressed this explicitly in his voice-over script, “Inside a satellite is a transponder which changes the frequency and amplifies the signal before sending it on” (“Satellites” animation).

When we learnt that “transponder” was a portmanteau (i.e., a merging of two words), the visual potential for morphing transmitter and responder together was obvious. Figure 4.10 shows the two words as they start to merge.
Figure 4.10. Screen shot of the transponder portmanteau.

This simple device was very helpful because it would have been extremely difficult to actually show how the signal's frequency is changed inside the transponder. The actual sequence was:

```
TRANSMITTER RESPONDER
TRANSMITTERESPONDER
TRANSMITTERESPONDER
TRANSMITTEESPONDER
TRANSMITTEESPONDER
TRANSMITSPONDER
TRANSMISPONDER
TRANSMPONDER
TRANSPONDER
```

The need to be able to visualise the [invisible] satellite signals provided additional opportunities for us to discuss the properties of these transmissions. Neil’s early attempts at representing a satellite signal involved moving brackets [ )))) ] which resembled a ripple on a pond. I suggested that he use a lengthening line [ ____ ] to show that the signals are constant rather than intermittent. Neil was agreeable but somewhat annoyed that he would need to recreate some of his imagery.

Neil clearly enjoyed the animation process. I often wondered if he was more interested in creating movement than learning about his topic. The following story illustrates
Neil’s enthusiasm when he inadvertently stayed back after school beyond 3:30 pm when a Storyboard session concluded:

I had my usual orchestra rehearsal and as the other children were coming in, Neil said he was “just finishing up”. I had my back to him and became distracted with the twenty-five musicians who had now arrived and were tuning up. Fifteen minutes later, I noticed that Neil was still there working away and that he had created thirty-two slides (Researcher reflection, 11th August 2011).

I asked Neil to elaborate on his learning during the debriefing session:

**Brendan:** How do you think you learnt compared to if you did something that wasn’t on a computer. Like if you were making posters or writing a normal sort of assignment? Do you think you would have learnt as much or do you think it was…do you think this was a, a better or worse way to go about it?

**Neil:** I think like a visual presentation like on a computer, you can just explain it more and it’s more entertaining and more like…you, you have a lot more ways to go about it where…whether…if you do it on like a poster or a piece of paper, I think your choices would be much, much more limited in how you’d want to do it or set it out (Debriefing session 2, 22nd December 2011).

Neil’s enthusiasm often turned into frustration as he rarely heeded my advice to get his imagery correct before creating movement through the “Insert duplicate slide” process. At one stage, Neil thought that he had finished but there were issues with his imagery that we still had to resolve. “Today I actually found out that I haven’t finished, according to Brendan, which I’m not happy with” (Student reflection, 1st December 2011). The particular issue related to the background colour of outer space. Neil was using white rather than black and he had also applied a shadow. Figure 4.11 is a discarded screen shot from a complete series of 89 frames.
Neil was annoyed about having to redo this, but, once completed, he could see that his animation was more realistic using black for outer space. During the last session, there was still work to be done so Neil delegated these finishing touches to me: “I’ve instructed Brendan and told him what I need to be done and he’s going to be helping me finish it which is really good” (Student reflection, 8th December). I asked Neil how he felt about the issue of co-authorship during the group’s debriefing session:

**Brendan:** How did you feel about me working on your work? Do you think it took away from it being yours as much or were you just happy that you had help?

**Neil:** Well, I think I really appreciate that Brendan could help me and I just, it just felt like it took away a bit of the pressure and I don’t feel that… as if it… my project was being taken away by me. I still think, Brendan helped out a lot but I still did a lot, umm, with it. And he just helped me and just guided me as well and yeah and I really appreciate that (Debriefing session 2, 22nd December 2011).

Neil developed a deep understanding of everything he presented in his animation. The “Basic understanding” assessment in his conceptual consolidation rubric is because we left out some issues to make the topic more manageable. Such issues included the geosynchronous orbit that keeps each satellite in position. Table 4.8 is Neil’s final conceptual consolidation rubric.
### Table 4.8

Neil’s final conceptual consolidation rubric

<table>
<thead>
<tr>
<th>Uses correct terminology</th>
<th>With assistance</th>
<th>Simplified terminology</th>
<th>Some correct terminology</th>
<th>Actual terminology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identifies relevant variables</td>
<td>Not apparent</td>
<td>With assistance</td>
<td>Basic understanding</td>
<td>Deep understanding</td>
</tr>
<tr>
<td>Identifies relationships between variables</td>
<td>Not apparent</td>
<td>With assistance</td>
<td>Basic understanding</td>
<td>Deep understanding</td>
</tr>
<tr>
<td><strong>Self-assessment scale.</strong> Does the student think that they understand their topic?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

If Neil was to start another animation now he would be much more efficient as he understands the importance of building appropriate imagery before attempting to animate it. A summary of Neil’s conceptual journey is presented in Table 4.9.

### Table 4.9

Summary of Neil’s conceptual journey

<table>
<thead>
<tr>
<th>Neil - Grade 6 boy</th>
<th>Prior knowledge</th>
<th>Issues or obstacles</th>
</tr>
</thead>
</table>
| **Satellites** | "My topic is satellites and I really don’t know much about them except they’re used for transmitting signals to devices around us, say, for cable TV, or, umm, GPSs and, so, yeah. That’s all I know about them."

Neil needed a relevant question to focus his efforts so I asked him; “How many satellites does it take to transmit a signal around the world?”

<table>
<thead>
<tr>
<th>Choice of metaphor</th>
<th>Implementation of metaphor</th>
<th>Relevant variables</th>
</tr>
</thead>
</table>
| ![Satellite diagram](image) | ![Earth and satellite diagram](image) | - Straight lines (transmissions)
- Round globe (Earth)
- Transponders perpetuating signals as transmission responders |

<table>
<thead>
<tr>
<th>Behind the scenes</th>
<th>Different perspectives</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neil introduced the character Fat Jeffery to humanize his animation. This character could have been considered to be superfluous but it helped motivate Neil and also focused the animation around the transmission of television signals.</td>
<td>Neil had planned to include compatibility issues between various satellites. These issues related to configurations determined by company and country protocols, rather than true functionality, so I encouraged Neil to abandon this idea.</td>
<td>Even though I considered Neil to have succeeded with his animation task, I assessed him as having a “Basic understanding” of relevant variables as we didn’t explore important issues such as geosynchronous orbits which keeps each satellite in position.</td>
</tr>
</tbody>
</table>
## A portrait of Magnus

Magnus was a Grade 5 boy who chose to investigate "Electromagnetic fields". Table 4.10 contains the transcripts of Magnus' three videos.

### Table 4.10

**Magnus' video transcripts for “Electromagnetic fields”**

<table>
<thead>
<tr>
<th>Prior knowledge video</th>
<th>Transcript</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Magnetic field image" /></td>
<td>Umm, my topic is magnetic fields and, umm, all I know about magnetic fields is they are invisible but powerful and, yeah, that's pretty much all I know.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Completed explanatory animation</th>
<th>Transcript</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image2.png" alt="Completed explanatory animation" /></td>
<td>A magnetic field is an area where the forces of attraction from a magnet are working. An electromagnetic field has the same effect as a magnetic field but it can be turned on and off by stopping the electricity which it requires. Electric motors are one of the main uses of electromagnetic fields. Electric motors convert electrical energy into mechanical energy. The mechanical energy is normally used to turn things like wheels. A generator is like an electric motor used the other way where mechanical energy is converted to electrical energy. Additional uses of electromagnetic fields are LCD screens and electromagnetic cranes.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Director's commentary</th>
<th>Transcript</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image3.png" alt="Director's commentary" /></td>
<td>I completely changed my topic, from...well not completely. I changed my topic from 'Magnetic field' to 'Electromagnetic field' because I thought 'Electromagnetic field' was more interesting. I also liked it how, umm, Brendan, ah, added some pictures into my animation so it looked better. And with the switch and the fan and stuff, I reckon I did a pretty good job of that. And I also like the LCD screen with the electromagnetic crane. I thought that was a pretty good end.</td>
</tr>
</tbody>
</table>
Introducing Magnus and his topic

Magnus was one of the youngest participants in the Storyboard project but his advanced computer skills gave him confidence regarding his ability to create an explanatory animation. Magnus was also quite sensitive. I had seen him in various situations over the years, during our regular music classes and also in the schoolyard, where he required reassurance if he felt he was being misunderstood. In spite of his confidence on the computer, I knew from the beginning of the project that I would need to spend more than 1/8 of my time with Magnus.

During the initial selection process for this project, Magnus proposed that his topic would be “Magnetism”. When I gave Magnus the “Plain language statement” and “Consent form” to take home to his parents just prior to commencing the first Storyboard session, he said that “Magnetic fields” was a more accurate name for his topic. This subtle change alluded to the issue of whether his animation would be about what magnets are or what magnets do?

During the first session, Magnus stated that all he knew about magnetic fields was that they are “invisible but powerful” (Prior knowledge video, 21st July 2011). Magnus also knew that metal was important but he had yet to clearly articulate whether metal was a cause or effect of a magnetic field, “Magnetic fields are normally caused by metal, not always but normally” (Student reflection, 21st July 2011). My initial reflection after this session was that “I have no additional knowledge about magnetic fields myself other than what I learnt in school” (Researcher’s reflection, 21st July 2011). What I remember from high school about magnetic fields was:

- Opposites attract
- Like charges repel
- Some metals can become magnetised when exposed to magnets
- Magnets can lose their strength if incorrectly stored

Creating the ZPD with Magnus

Magnus’ need for assistance, and reluctance to work on his own, occasionally made it hard for me to share my time with the other participants. Hence I decided to offer Magnus his own space. The Music room where the study was conducted consisted of a large room and a much smaller room with a drum kit and a computer. By offering Magnus this space, he was able to avoid the temptation to ask the other children to
look at his work. Although it is normal for children to want to share their work, Magnus’ frequency of wanting to share had become counterproductive for himself and the other students. As the door to Magnus’ room contained a large window, Magnus was still able to see and hear the other children but he wasn’t as likely to want to talk and he could then focus on his work. Having Magnus in a separate space also encouraged him to engage with the computer itself as a mediating tool, rather than relying on the social network as mediators. When I visited Magnus’ workspace it also felt a little more special for both of us as we would have something to share via updates around our discussions.

The computer in Magnus’ room was one of the two systems within the school that had professional video editing software installed. As such, Magnus became the first student within the study to open the video editing software. Although it would be a long time before we actually needed to render anything using this software, I felt that Magnus’ interest was waning and he needed to be reminded that his final animation would be a video file. His first use of Adobe Premiere Pro was little more than creating a file called “Magnetic fields” and designing a title of the same name. The significance of this event was that I told Magnus that “none of the other children had commenced the video editing stage”, a fact that clearly delighted him.

**Magnus’ conceptual journey**

Finding suitable visualisations was a key issue in the early stages of Magnus’ animation. I remember playing with magnets and iron filings when I was in high school so I asked Magnus if he had ever worked with iron filings to observe how they move when placed within a magnetic field. He replied that he had never tried this. Magnus incorporated this idea into his animation, commenting “I now know that iron filings can be pulled in by a magnet with an invisible field called, magnetic field” (Student reflection, 28th July 2011).

By the fourth session, it was becoming increasingly apparent that we had to introduce some new ideas, as Magnus would make superficial changes each week such as changing the background colour of the slides. Figure 4.12 is a screen shot from Session 4 with three iron filings depicted around a magnet.
The iron filings imagery in Figure 4.12 was the first time Magnus had introduced lines to show the direction of a magnetic field. The ubiquitous nature of lines to depict forces is such that “there is no absolute ‘right’ or ‘wrong’ convention to describe force” (Tytler, Hubber, Prain & Waldrip, 2013, p. 36). Figure 4.12 was not a stand-alone static diagram but, rather, an extract from a series of frames. Watching Magnus’ series of frames clearly showed the direction of the magnetic field as the iron filings moved progressively closer towards the magnet in the middle, thus making the lines redundant.

Magnus addressed this relationship between animation and still images during the final debriefing session described in the following exchange. During the group discussion the children had started thinking about a picture that Ingrid was drawing of Evel Knievel. Magnus’ enthusiasm for the animation medium actually kept the discussion on track and drew Molly and Maria (both a year older) into a discussion about older forms of animation (e.g., the flick book), and how much more interesting these are than static ‘bits of paper’:

**Brendan:** Do you have any comments about animation compared to doing a more traditional type of project?

**Magnus:** Animation was so much funner [sic].

**Ingrid:** Yeah.

**Molly:** Yeah.

**Magnus:** More fun.
Brendan: What? Just in general? You just think it was more fun because it was on a computer or because it was movement?

Magnus: Because it was movement.

Sunny: Because it was moving.

Molly: I like animation.

Sunny: Well I find bits of paper [referring to the blank pieces of paper that I had distributed to each child] just sitting there like...I couldn't be bothered reading this.

Magnus: A bit more like...

Ingrid: I couldn't be bothered looking at that.

Magnus: And also.

Ingrid: It's Evel Knievel [that she had just drawn].

Molly: People are falling asleep [as doodling on their pages had a relaxing effect on the children].

Sunny: I was about to fall asleep.

Magnus: I like doing books where you draw things at the bottom.

Maria: It's like fling books.

Magnus: Yeah whatever they're called. And then, and then you go like this and then you see it moving.

Ingrid: This is my final product.

Molly: I like animations because they're pretty cool to watch (Debriefing session 1C, 15th December 2011).

As Magnus’ learning path evolved, I felt that his animation would require some understanding of electricity if we were going to explain how magnets actually work. Beaty (1995) has noted that electricity can be a proverbial can of worms for a variety of reasons as electrical phenomena can vary dramatically depending on the materials involved. Beaty levels the blame for children’s misconceptions about electricity squarely at the simplistic explanations offered to children through many of the very
textbooks that teachers rely upon in the early years\textsuperscript{1}. I had already decided prior to the current study that simplistic explanations were to be avoided in preference to refining a topic so that topics could become more specialised and, therefore, manageable.

It was at this point that we discussed changing the topic. The new topic of “Electromagnetic fields” could then focus on what an electromagnetic field is rather than how it works. Paradoxically, by adding the word electromagnetic we could avoid having to explain electricity. Magnus seemed to immediately grasp the key point that electromagnetic fields can be turned on and off. This new focus on how electromagnetic fields differ from magnetic fields made the explanation more manageable and became a turning point for Magnus as he could then relate this new concept to a pre-existing one (i.e., the functionality of switches). Paradoxically, we expanded the number of variables within the animation by refining the topic, as the variable of “on” and “off” didn’t apply to magnetic fields.

Defining the scope of Magnus’ animation was an issue up until the very end of the project. Throughout various discussions, we had agreed to avoid using cross-sectional imagery but in the end, I decided that this would have resulted in a superficial treatment of the topic. Figure 4.13 shows Magnus’ rotating fan without using cross-sectional imagery as this sequence offered no explanation as to the inner workings of the motor.

\begin{figure}
\centering
\includegraphics[width=0.2\textwidth]{fan_imagery.png}
\caption{Screen shot of fan imagery.}
\end{figure}

\textsuperscript{1} There are too many examples in Beaty’s critique to list here, which further justified my choice to avoid presenting Magnus with simplistic explanations about electricity. I was acutely aware of my own limitations in this area, even though I have repaired many electrical devices in my time using my trusty soldering iron.
Magnus was very pleased with his animation of the fan sequence and concluded that his work was over, “Today I made a fan which is a really good visual effect as a electric motor and I have finished” (Student reflection, 7th December 2011). My reflection was that, “The fan is very effective at showing the rotation of an electric motor but I still think that we need to go inside the motor if we are to show the similarities between electric motors and generators” (Researcher’s reflection, 8th December 2011). Magnus’ animation was far from finished as the cross-sectional imagery still had to be designed. As this was the last animation session, I had to finish the cross-sectional imagery myself which took several hours as I had to research what were the minimal components to be included. Figure 4.14 shows an electric motor with a battery providing the power to turn a wheel.

![Figure 4.14. Screen shot of electric motor imagery.](image)

Figure 4.14 shows how generators convert mechanical energy into electrical energy.

![Figure 4.15. Screen shot of electrical generator imagery.](image)

Figure 4.15. Screen shot of electrical generator imagery.
Retaining the same screen position for the common components between motors and generators visually reinforced the point that electric motors and generators operate using the same principle (i.e., that mechanical energy can be used to create electrical energy and vice-versa).

There are two substitutions between Figures 4.14 and 4.15:

1. The battery is replaced with a light globe. This is to show that a battery provides energy in contrast to a light globe, which requires energy.
2. The wheel attached to the bottom of the axle that was turned by the electrical energy is now turned by the mechanical energy (i.e., wind or water).

Using on-screen text for “wind” and “water” avoided the need to animate flowing water or blowing wind as the movement of the wheel was sufficient to show that it was wind or water causing the rotation. I reflected at this time that it was the new terminology that enabled Magnus’ conceptual consolidation to continue, “now that mechanical energy and electrical energy (electricity) have become part of his explanation” (Researcher reflection, November 10th 2011).

The connection between electric motors and generators became explicit when Magnus stated in his final voice-over script that, “A generator is like an electric motor used the other way where mechanical energy is converted to electrical energy” (“Electromagnetic fields” animation). “Used the other way” (ibid) was the result of our discussion about the need to be very careful with the voice-over script. We avoided the phrase in reverse during the comparison between electric motors and generators as the commonality is about the order and organisation of the components and not the direction of the rotating shaft. Reverse has a spatial, literal meaning when talking about motors.

Discussions such as these helped Magnus to fine-tune his pedagogical awareness. This was also borne out by his concluding remark in the following discussion:

**Brendan:** How did you see the directors’ commentaries? What did, what you think they were?

**Magnus:** I thought they were just were...I thought they were just...what...

**Brendan:** Like a recap?

**Magnus:** Yeah. Like that.
Ingrid: Just for an idea of what the director of the animation was thinking while he was making the animation.

Brendan: And why do you think, why do you think I might care about such things?

Magnus: For umm, reference, for later on to see how kids learn (Debriefing session 1B, 15th December 2011).

My subsequent reflection during the compilation of Magnus’ portrait has caused me to reconsider what a metaphor is. In particular, both the electric motor and the generator were depicted as cross-sectional diagrams in the animation. If these representations were referring to the actual items under discussion, where was the metaphor? Metaphors are comparisons so the metaphorical use still applied, as one was a metaphor for the other, and vice-versa. This comparison helped concretise Magnus’ understanding of electromagnetic fields as he learnt to paraphrase electromagnetic functionality, independent of whether the electromagnetic field required electrical energy or generated it.

I extended the metaphor in the fourth session when “I used an electric guitar to demonstrate that an electromagnetic field can be created using magnets” (Researcher reflection, 18th August 2011). My reflection on this event in 2014 is that the hallmark of electromagnetic fields is not the ability to be switched on and off, but the ability to change one type of energy into another. A passive guitar pickup, much like a microphone, creates electricity but it doesn’t require electricity. It is the mechanical energy involved in playing the guitar strings, or singing into a microphone, that creates the electrical current.

Table 4.11 is Magnus’ final conceptual consolidation rubric. During the debriefing session, Magnus helped evolve the “Self-assessment” scale within the conceptual consolidation rubric as he felt that the previous construct (which only had four categories of “No”, “Not really” “Basic understanding” and “Yes”) was too limiting. Magnus proposed a scale of 1-to-10 so I implemented Magnus’ suggestion by calibrating this new scale for all of the children’s final rubrics (the rubrics in the children’s weekly reviews were assessed prior to this so they have retained the original, 4-point scale).
Table 4.11
Magnus’ final conceptual consolidation rubric

<table>
<thead>
<tr>
<th>Uses correct terminology</th>
<th>With assistance</th>
<th>Simplified terminology</th>
<th>Some correct terminology</th>
<th>Actual terminology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identifies relevant variables</td>
<td>Not apparent</td>
<td>With assistance</td>
<td>Basic understanding</td>
<td>Deep understanding</td>
</tr>
<tr>
<td>Identifies relationships between variables</td>
<td>Not apparent</td>
<td>With assistance</td>
<td>Basic understanding</td>
<td>Deep understanding</td>
</tr>
<tr>
<td>Self-assessment scale. Does the student think that they understand their topic?</td>
<td>1 2 3 4 5 6 7 8 9 10</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The reason Magnus’ conceptual consolidation rubric isn't marked higher is that his topic was quite difficult and there were many issues that we didn't cover such as phasing, polarity and AC/DC current. A summary of Magnus’ conceptual journey is presented in Table 4.12.

Table 4.12
Summary of Magnus’ conceptual journey

<table>
<thead>
<tr>
<th>Magnus - Grade 5 boy</th>
<th>Prior knowledge</th>
<th>Issues or obstacles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electromagnetic fields</td>
<td>“Umm, my topic is magnetic fields and, umm, all I know about magnetic fields is they are invisible but powerful and, yeah, that's pretty much all I know.”</td>
<td>The original “Magnetic fields” topic needed to become more specific and manageable for Magnus so his topic was amended to “Electromagnetic fields” on 1st September 2011.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Choice of metaphor</th>
<th>Implementation of metaphor</th>
<th>Relevant variables</th>
</tr>
</thead>
</table>
| ![Image of choice of metaphor](image) | ![Image of implementation of metaphor](image) | • Switches  
• On and off  
• Movement of shafts  
• Transfer of energy  
• Changing types of energy |

<table>
<thead>
<tr>
<th>Behind the scenes</th>
<th>Limitations</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Some of Magnus’ imagery required a cross-sectional view for further explanation, such as the electric motor / generator. Other examples of electromagnetic fields, such as electric cranes and LCD screens, were able to remain as integrated wholes.</td>
<td>Although North and South are depicted in the electric motor and generator imagery, the issue of polarity was bypassed through the renaming of the topic. Polarity could not have been avoided if the topic had remained as “Magnetic fields”.</td>
<td>Magnus demonstrated his understanding of electromagnetic fields when he was able to paraphrase the functionality of electric motors and generators, independent of whether the electromagnetic field required electrical energy or generated it.</td>
</tr>
</tbody>
</table>
A portrait of Molly

Molly was a Grade 6 girl who initially chose to investigate “Chemical reactions”. Table 4.13 contains the transcripts of Molly’s three videos.

Table 4.13

<table>
<thead>
<tr>
<th>Prior knowledge video</th>
<th>Transcript</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>My topic is chemical reactions.</td>
</tr>
<tr>
<td></td>
<td>I don't really know much about chemical reactions but when you put two things together it makes something different, and that's practically all I know.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Completed explanatory animation</th>
<th>Transcript</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Atoms are the building blocks of matter. A molecule is a group of atoms. Atoms are sometimes named after the first letter:</td>
</tr>
<tr>
<td></td>
<td>They are sometimes based on the first two letters:</td>
</tr>
<tr>
<td></td>
<td>Li for Lithium.  Ti for Titanium.</td>
</tr>
<tr>
<td></td>
<td>Sometimes the letters have nothing to do with the element:</td>
</tr>
<tr>
<td></td>
<td>Au for Gold.  Ag for Silver.</td>
</tr>
<tr>
<td></td>
<td>A number following the element refers to the quantity of those atoms. The number comes after the element. For example, H2O means two hydrogens and one Oxygen, H2O4S means two hydrogens, four oxygens and one sulphur</td>
</tr>
<tr>
<td></td>
<td>The order in which the elements are written usually follows the rule developed by Edwin Hill in 1900. According to this rule, when you have Carbon it goes first, Hydrogen is second and the rest are in alphabetical order.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Director’s commentary</th>
<th>Transcript</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I changed from topic from “Chemical reactions” to “Chemical bonds” to “Molecular naming conventions.”</td>
</tr>
<tr>
<td></td>
<td>I liked how it went and how I made the letters light up when they were mentioned.</td>
</tr>
<tr>
<td></td>
<td>Brendan helped me with the animation and I like how he did some of the picturing.</td>
</tr>
<tr>
<td></td>
<td>So if you need to ever to learn about naming conventions just go to my animation.</td>
</tr>
<tr>
<td></td>
<td>Edwin Hill helped me get this animation correct and helped me get the actual information in order.</td>
</tr>
</tbody>
</table>
Introducing Molly and her topic

Molly had a friendly, positive attitude and was always eager to learn and challenge herself with new experiences. Molly was the only 2011 participant who was also involved in the 2010 pilot study. During the first session, Molly got straight to work and devised the following questions as her slide headings:

- What is a chemical reaction?
- Why do we do chemical reactions?
- How did we find out about chemical reactions?
- An example of a chemical reaction (PowerPoint file, 21st July, 2011).

Slide headings are generally associated with more typical PowerPoint presentations but I knew that Molly was thinking in terms of creating various animation scenes as she had been through this process before. Molly also knew at this early stage that her topic would probably require some tweaking:

Chemical reaction is such a broad topic. I have to find out the basics of chemical reactions and cut it down, to... say... two different things and instead of doing heaps of like...what it is, I should do it like, two different types of chemical reactions and put detail into it. Lots and lots of detail (Student reflection, 21st July 2011).

My own prior knowledge was limited to what I had learnt in High school where I found that I was much better at Physics than Chemistry. I remembered the Periodic Table of the Elements quite vividly and thought that there might be some interesting visual possibilities if we looked at the valency of various elements.

A single animation covering Chemical reactions would always have been too big but we didn't realise how big until later. We considered changing the topic to “Chemical bonds” during the 8th session. This would also have been too big as there were several sub-categories such as covalent, ionic and so on.

Creating the ZPD with Molly

Although other students also changed topics during the project, the mutual ZPD that Molly and I were in seemed to revolve around the various discussions about modifying her topic. There was a time when we thought we could come up with a novel way to
represent chemical bonds when we first encountered Lewis-style dot diagrams. Figure 4.16 is a Lewis-style dot diagram showing how molecules can be represented as a combination of elements with corresponding atomic bonds.

![Lewis-style dot diagram for water](http://commons.wikimedia.org/wiki/File:Water-2D-flat.png)

*Figure 4.16. Lewis-style dot diagram for water.*

It was initially exciting to read that there are pre-existing representation traditions such as Lewis-style dot diagrams. Ideally, Molly would create a new system but this might be unrealistic” (Researcher reflection, 8th September 2011). It turned out that these diagrams don't reduce the complexity of chemical bonds so we decided to experiment with some other ideas. Molly was very patient and willing to change so we considered using a jigsaw metaphor. Figure 4.17 shows jigsaw pieces with a defined number of male or female parts¹ to represent how different atoms can become molecules depending on their valency.

![Screenshot of discarded jigsaw metaphor](http://example.com/jigsaw.png)

*Figure 4.17. Screenshot of discarded jigsaw metaphor 18th August 2011.*

¹ The terms *male* and *female* are used here in a similar way to electrical audio connections where the male parts are extended and the female parts are recessed.
I suspect that my incomplete recollection of the periodic table from High school chemistry left me equating this [valency] to positive and negative numbers. I'm now fairly sure that this isn't the case so the jigsaw puzzle imagery from last week is not the best representation for this concept. There is a money analogy that I'll mention [during the next session] as one possible alternative. It involves various denominations of coins that can be combined to add up to one dollar (thus avoiding negative numbers) (Researcher reflection, 25th August 2011).

When I suggested that positive and negative might not be appropriate terminology, Molly was very gracious, considering that it was I who had first suggested these terms only a few weeks earlier. I noted that the "new analogy of various coins making up a dollar was well received so this could be our way forward" (Researcher reflection, 1st September 2011). Molly appeared to have no trouble abandoning the negative and positive terminology saying, "I realised that you can't do positive and negative for my presentation because there's no such thing in chemical language about positive and negative" (Student reflection, 1st September 2011). Further reflection about the validity of negative and positive caused me to wrestle with the issue of whether I could really support Molly with her topic as noted in my Researcher's reflexive journal, 17th October 2011:

I am considering whether Molly might be better changing to a completely different topic such as the musical rhythms of swing and straight. She is the only Storyboard 2011 participant who was also part of the 2010 pilot study and her topic then was the musical convention of "Sharps and flats". Not only would a new topic be easier, but I read a statement in the International Handbook of Research on Conceptual Change (2008) that made me question my ability to be of real assistance to her. "Instructional approaches compound the problem when they present the tenants of the atomic molecular theory as a set of facts rather than as an explanatory model" (Wiser & Smith, 2008, p. 220).

My self-doubt occurred during Molly's one-month absence (i.e., two Storyboard sessions and two weeks of school holidays). "I spoke to Molly outside of a Storyboard session as I hadn't had the opportunity for over a month. She wanted to keep a chemistry focus so we are looking at Chemical bond naming conventions" (Researcher's reflexive journal, 18th October 2011). Ultimately, a topic change was in order and having found Hill's rule, we were finally confident that we had a topic that could be adequately covered. Our goal was to simplify the topic without being simplistic.
Molly’s conceptual journey

When the topic evolved into “Molecular naming conventions”, the previous metaphors were abandoned as they were no longer relevant. These discarded metaphors, however, had still served a valuable purpose for Molly’s learning as they provided a context for us to articulate the variables involved in her topic and to discuss how these might fit together as a model. This approach was consistent with the notion that “chemistry as a discipline is dominated by the use of models and modelling” (Coll & Taylor, 2002, p. 175).

To assist with model development, I introduced Molly to Hill's rule for naming molecular bonds. This consisted of three short guidelines that Molly was able to include in her reference slide (i.e., the final frame at the end of an animation where information is left on the screen for possible use in classroom discussion). Figure 4.18 states Hill’s rule as three sequential guidelines:

<table>
<thead>
<tr>
<th>Hill’s rule</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Carbon first</td>
</tr>
<tr>
<td>2. Hydrogen second</td>
</tr>
<tr>
<td>3. The rest are in alphabetical order</td>
</tr>
</tbody>
</table>

Figure 4.18. Hill’s rule as a concluding reference frame.

The animation task for Molly then became a process of reverse engineering where she could devise the most affective way the lead up to Hill’s three guidelines. Molly introduced her animation by stating that, “Atoms are the building blocks of matter” (“Molecular naming conventions” animation). Figure 4.19 depicts literal building blocks containing the chemical element abbreviations accompanying the figurative speech of Molly's voice-over script.
The notion of atoms combining and bonding into molecules was then handled without reference to electrons or valency. The main consideration was now about achieving visual clarity. “Today I experimented trying to find which colours would suit the elements for highlighting” (Student reflection, 8th December 2011). Figure 4.20 shows how the red oval shape acts as a grouping device for the chemical element symbols:

![Figure 4.20. "Molecular naming conventions" screen shot 8th December 2011.]

The decision to use the names and corresponding abbreviations for the elements, rather than attempting to represent them graphically, made the task more manageable. I noted that labelling and naming appears to be one of the easiest representational tasks as this process is often arbitrary:
Molly's reflection about how she is going to "write the atoms instead of drawing them" is actually quite profound. Far from language being the ultimate form of expression, Molly chose words as an easier option than the more difficult task of representing atoms by drawing their structure (Researcher reflection, 20th October 2011).

During the debriefing session, Molly had some insight and opinion about the issue of the ideal class size for this project:

**Brendan**: I mentioned to you all that umm, that last year I did the same project but the difference was I didn’t get the information along the way. I just got the final animation, right? Two things about the comparison between them and you: Firstly, I told you that there were eighteen of those children.

**Molly**: And I was one of them.

**Brendan**: And you were one of them. Do you have any comment before I say another word?

**Molly**: I like it with eight people because it’s more...

**Maria**: Individual.

**Molly**: You get to go, you get to learn more and you're more...

**Sunny**: Focused.

**Molly**: You're more "in it" and get to know people better.

**Brendan**: There were a few times like with Grade 5 camp that only half of us were here and I think that was even better.

**Molly**: Yeah (Debriefing session 1C, December 15th 2011).

I have since concluded that a class size of four would have been optimal. Table 4.14 is Molly’s final conceptual consolidation rubric.
Table 4.14

*Molly’s final conceptual consolidation rubric*

<table>
<thead>
<tr>
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<td>Basic understanding</td>
<td>Deep understanding</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Self-assessment scale. Does the student think that they understand their topic?</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7.5</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
</table>

Molly’s modest self-assessment score of 7.5 may have been because she realised how difficult chemistry can be and remembered how much of the initial research was too difficult. My assessment in the first three rows of her rubric was higher than Molly’s self-assessment, as I looked at the topic that she actually presented. In that regard, Molly would agree that she understood her topic clearly, stating confidently, “if you need to ever to learn about naming conventions just go to my animation” (“Molecular naming conventions” director’s commentary).

Molly’s director’s commentary was the only one where we changed the video footage from the completed explanatory animation by speeding up one passage. This was because we didn't need as much time at this point to accommodate Molly’s comments.
A summary of Molly’s conceptual journey is presented in Table 4.15.

Table 4.15
Summary of Molly’s conceptual journey

<table>
<thead>
<tr>
<th>Molly - Grade 6 girl</th>
<th>Prior knowledge</th>
<th>Issues or obstacles</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Molecular naming conventions</strong></td>
<td>“My topic is chemical reactions. I don’t really know much about chemical reactions but when you put two things together it makes something different, and that’s practically all I know.”</td>
<td>This topic was originally “Chemical reactions” and then “Chemical bonds”. We concluded that these topics were too complex to adequately cover in a single animation so the topic was refined into “Molecular naming conventions.”</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Choice of metaphor</th>
<th>Implementation of metaphor</th>
<th>Relevant variables</th>
</tr>
</thead>
</table>
| ![Image](image) | ![Image](image) | • Atoms  
• Molecules  
• Valency  
• Hill’s law |

<table>
<thead>
<tr>
<th>Behind the scenes</th>
<th>Different perspectives</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>We explored several interesting metaphors during the initial phases of refining the topic. These metaphors involved jigsaw pieces to show which atoms can fit together and a currency metaphor to show how various coins (atoms) can be combined to make a whole dollar (molecule).</td>
<td>The evolution of this topic effectively shifted from the atomic level to the molecular level. Our willingness to change topics was an outcome of the belief that it is better to explain a specific topic carefully, rather than offer a simplistic explanation for a complex topic.</td>
<td>Molly made her topic substantially easier by using words for the elements rather than graphic representations. This led us to conclude that naming is relatively arbitrary whereas diagrams and models are deliberately functional.</td>
</tr>
</tbody>
</table>
A portrait of Ingrid

Ingrid was a Grade 6 girl who chose to investigate “Stringed instruments”. Table 4.16 contains the transcripts of Ingrid’s three videos.

Table 4.16

Ingrid’s video transcripts for “Stringed instruments”

<table>
<thead>
<tr>
<th>Prior knowledge video</th>
<th>Transcript</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>My topic is strings, and, umm, I know nothing about strings on the piano. And I’m probably going to do most of my research on strings on a piano more than a guitar.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Completed explanatory animation</th>
<th>Transcript</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stringed instruments such as piano and guitar have multiple strings but the science behind the pitch of the notes is the same for each string.</td>
</tr>
<tr>
<td></td>
<td>The pitch of a musical note is measured by its frequency which is the number of vibrations per second.</td>
</tr>
<tr>
<td></td>
<td>The variables of length, tension and mass combine to give each note it's frequency.</td>
</tr>
<tr>
<td></td>
<td>The longer the string, the lower the frequency. The shorter the string the higher the frequency.</td>
</tr>
<tr>
<td></td>
<td>The looser the string, the lower the frequency. The tighter the string the higher the frequency.</td>
</tr>
<tr>
<td></td>
<td>The thicker the string, the lower the frequency. The thinner the string the higher the frequency.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Director’s commentary</th>
<th>Transcript</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>My original animation was talking about &quot;Cell duplication&quot; but more than half way through researching the topic, I realised that it would be too hard and if we did animate it, it would just be a copy of something that we had already seen.</td>
</tr>
<tr>
<td></td>
<td>The formula itself is quite complicated but once you understand it and you've read over it a few times it's actually quite simple.</td>
</tr>
<tr>
<td></td>
<td>I realised it was a complicated formula but the variables are quite easy to understand.</td>
</tr>
</tbody>
</table>
Introducing Ingrid and her topic

Ingrid was known throughout the school for her acting abilities and she had also just landed a job on a TV commercial. Ingrid and I lived on the same block so we often ran into each other at the local park when walking our dogs. Through these informal encounters with Ingrid and her mother, I learned that Ingrid [initially] chose “Cell duplication” as her topic because she wanted something that sounded more academic to round out her school achievements. This proved to be a wise move as Ingrid’s application for a scholarship to a prestigious private high school was approved. Ingrid’s success might have had little to do with her choice of animation topic, but it does show what she was thinking around that time.

The [initial] “Cell duplication” animation was proceeding quite well as Ingrid had identified some of the key variables. Figure 4.21 shows how Ingrid understood that the chromosome divides inside the cell membrane before the membrane divides.

![Image]

Figure 4.21. “Cell duplication” screen shot 18th August 2011.

It wasn’t until halfway through the project that Ingrid decided to change her topic to “Stringed instruments”. Other children had refined their topics but Ingrid’s new choice was a completely different topic that equated to starting again. This pivotal event was captured in my reflection on the “Lesson plan” for Session 8 (Appendix E):
Session 8 had only half the class present due to a camp. This allowed me to have more time with the remaining four students. I had thought that Ingrid was almost ready for the final construction of her imagery once chromosomes had been investigated a little further. We came across a cell duplication animation at http://www.cellsalive.com/mitosis.htm (accessed 22nd September 2011). This animation was very effective as it also contained video of actual cells duplicating. The various phases of cell duplication could also be played separately as mini video segments to reduce cognitive load. Once we had viewed this animation, there appeared to be only three options open to us:

1. Recreate a similar animation using the new details we had just learned
2. Simplify the animation to make it easier to explain
3. Start a new topic

Recreating the animation was not very appealing as it would have been a lot of work with little reward considering that her representational ideas would have been derivative. Simplifying the animation grated against my pedagogical ideals, which were largely informed by Einstein's guideline to avoid oversimplification.

This left us with only one option, which was to start a new topic. I encouraged Ingrid with the fact that a 2010 Storyboard participant has also successfully changed topics even further into the project. I also mentioned that seven out of eight topics for the current project were scientific so it would be good to have more variety. She then proposed that we do something musical and "Stringed instruments" was soon chosen. This new topic is actually scientific, mathematical and musical (Lesson plans, 22nd September 2011).

Creating the ZPD with Ingrid

“Stringed instruments” was a topic about which I felt confident, due to my usual role as a music teacher. I told Ingrid that frequency is simply mass multiplied by tension. Before the next session, I did some further research to confirm that the formula was as simple as I had presumed. It turned out that the correct formula for measuring frequency was a lot more complicated as shown in Figure 4.22 (http://www.noyceguitars.com/Technotes/Articles/T3.html accessed 25/09/2011).
Prior to seeing Ingrid at the next session, I had reflected that this formula is “beyond what most Grade 6 students cover in their mathematics curriculum. As we are around the halfway point in the Storyboard project it is probably better to just give her the formula” [rather than have her work it out for herself] (Researcher reflection, 14th October 2011). I had decided that in certain situations, literally giving a student the answer can be perfectly valid as long as they still engage with it. I anticipated that Ingrid would “experiment and play with this formula, especially if she chooses to animate the variables in real time with synchronised audio” (ibid). Giving Ingrid the formula was significant because the mediating tool for her turned out to be the frequency formula itself.

Figure 4.22 was reconstructed in PowerPoint using letters and lines so we could change colours, sizes and position at our discretion. Having the formula constantly on the screen meant that Ingrid was never required to memorise the formula. This was also important because it allowed her to discuss each variable separately without the need to consider each variable simultaneously.

When I first encountered this formula, I inputted some measurements to ensure that it was correct. Figure 4.23 shows my initial attempts at testing this formula using actual numbers to determine the units of measurement.
Figure 4.23. Testing the frequency formula with actual numbers.

Figure 4.23 is from the PowerPoint file “201011b.ppt” which I had prepared for Ingrid. It was never intended to make its way into the animation but it led to the idea of what I now call a reference frame (which is when the final frame is frozen whilst displaying additional or summary information). This led to the creation of the Figure 4.24, which became the final image in Ingrid’s animation.

During a discussion about how to animate the formula, I had suggested showing and then replacing the T (tension), M (mass) and L (length) symbols with actual strings and then show how these variables affect the frequency using changing audio in real time. Ingrid came up with an even better idea as follows:
The original idea of replacing the variable "L" with a string of varying length and so on for tension and mass would have resulted in three strings being visible on the screen. Ingrid has decided to have one longer string more prominently displayed on the screen and then to colour code each variable in turn (Researcher reflection, 27th October 2011).

Ingrid experimented with various instruments in the Music room during the animation sessions. "I helped her dismantle an actual piano during the session so she could play around with it and see the relative string lengths" (Researcher reflection, 14th October 2011). This clearly influenced Ingrid’s depiction of the strings of varying length that were arranged vertically to resemble an upright piano as shown in Figure 4.25.

\[ F = \frac{1}{2L} \sqrt{\frac{T}{M}} \]

*Figure 4.25. Strings of varying lengths represented as piano strings.*

Loose strings were harder to draw but we knew that the vibrations couldn't possibly be in real time or there would have been over a thousand vibrations every second and we were limited to 25 frames per second. Our mutual interest in these animation design issues was simultaneously conceptual and pedagogical.

**Ingrid’s conceptual journey**

The opening scene in Ingrid’s animation shows that she understood the commonality of vibrating strings, independent of which instrument they might belong to, as shown in Figure 4.26. “Stringed instruments such as piano and guitar have multiple strings but the science behind the pitch of the notes is the same for each string” (“Stringed instruments” animation).
Ingrid’s voice-over script was careful and deliberate in terms of how she presented her terminology. “The pitch of a musical note is measured by its frequency which is the number of vibrations per second” (“Stringed instruments” animation). Immediately after recording these words, Ingrid commented that “I also wanted to put in the words *pitch* and *frequency* but in two different places depending on whether I wanted to use…focus on the musical side of it or the scientific side” (Student reflection, 10th November 2011). My reflection after that session was that “It is also significant that Ingrid identified pitch and frequency as being different expressions and measures of the same variable. She has contextualised each term depending on the musical or scientific emphasis of the explanation which is excellent” (Researcher reflection, 10th November 2011).

With only two sessions remaining, the impending deadline for the project surfaced the issue of co-authorship. As the last session was used for the debriefing session, there was really only one session remaining:

I had Ingrid in mind when I asked the class how they felt about the possibility of me working on the animations between sessions to ensure that the work gets finished with only two sessions to go. This has always been a delicate issue for me in my dual role as teacher/researcher but the children were unanimous in agreeing that my assistance was welcome and probably essential (Researcher reflection, December 1st 2011).

During the debriefing session, our proximity as collaborative partners surfaced the idea that directors’ commentaries might be generative and not merely descriptive. To conclude her director’s commentary, Ingrid said that, “the formula itself is quite complicated but once you understand it and you’ve read over it a few times it’s actually quite simple” (“Stringed instruments” director’s commentary). I asked Ingrid if she
thought that she understood the formula and she said that she did. I questioned her about this further and asked her if she knew what the square root symbol meant [I just pointed at the symbol without naming it]. She could not answer. I then told Ingrid the name of the symbol. Ingrid claimed to have heard of it but could not remember what it meant. She could offer no answer when I asked her if she knew the square root of 25. I concluded the discussion by reassuring her that understanding the actual effect of these variables on the pitch of stringed instruments was sufficient for our purposes. Ingrid then proceeded to record an additional sentence to conclude her commentary in a more cautious and measured tone. “I realised it was a complicated formula but the variables are quite easy to understand” (Researcher’s reflexive journal, 15th December 2011).

Ingrid demonstrated a consolidated understanding of frequency as she correctly identified the variables of tension, length and mass and the relationships between these variables. The fact that Ingrid hadn’t been introduced to the square root symbol in her regular classroom prior to this didn’t diminish her understanding of how the three variables affect the frequency of strings on stringed instruments. Ingrid’s partial understanding of the formula was a mathematical issue that went above and beyond the requirements of conceptual consolidation for her particular topic. I marked Ingrid’s final conceptual consolidation rubric accordingly in Table 4.17.

Table 4.17
Ingrid’s final conceptual consolidation rubric

<table>
<thead>
<tr>
<th>Uses correct terminology</th>
<th>With assistance</th>
<th>Simplified terminology</th>
<th>Some correct terminology</th>
<th>Actual terminology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identifies relevant variables</td>
<td>Not apparent</td>
<td>With assistance</td>
<td>Basic understanding</td>
<td>Deep understanding</td>
</tr>
<tr>
<td>Identifies relationships between variables</td>
<td>Not apparent</td>
<td>With assistance</td>
<td>Basic understanding</td>
<td>Deep understanding</td>
</tr>
<tr>
<td>Self-assessment scale. Does the student think that they understand their topic?</td>
<td>1 2 3 4 5 6 7 8 9 10</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A postscript for Ingrid’s journey occurred when she walked in during the second (i.e., final) debriefing session. I gave Ingrid special attention for being the first to complete her director’s commentary by sharing this with the group as a model for their own process:
The director’s commentary you’ve done is the first one that I’ve actually finished [I had edited and mastered Ingrid’s commentary and combined it with the original video footage]. And that’s what I’m up to now for you guys, is to actually find out what a director’s commentary looks like and then record your own. It goes with the imagery. So we’re going to watch yours now (Debriefing session 2, December 16th 2011).

A summary of Ingrid’s conceptual journey is presented in Table 4.18.

Table 4.18
Summary of Ingrid’s conceptual journey

<table>
<thead>
<tr>
<th>Ingrid - Grade 6 girl</th>
<th>Prior knowledge</th>
<th>Issues or obstacles</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stringed instruments</strong></td>
<td>“My topic is strings, and, umm, I know nothing about strings on the piano. And I’m probably going to do most of my research on strings on a piano more than a guitar.”</td>
<td>Ingrid’s topic ended up changing completely from “Cell duplication” as that topic was too big and would have involved recreating existing animations with limited learning gains.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Choice of metaphor</th>
<th>Implementation of metaphor</th>
<th>Relevant variables</th>
</tr>
</thead>
</table>
| $F = \frac{1}{2L} \sqrt{\frac{T}{M}}$ | $F = \frac{1}{2L} \sqrt{\frac{T}{M}}$ | • Length  
• Tension  
• Mass  
• Frequency  
• Pitch |

**Behind the scenes**

The change of topic for Ingrid in session 8 was the result of her previous topic challenging my pedagogical values. In particular, I did not want her to have to use a simplistic explanation or merely copy a more sophisticated animation that we had encountered.

**Different perspectives**

Due to the complexity of the formula and the change of topic halfway through the project, I gave Ingrid the answer, i.e. formula. It was then up to her as to which order she chose to address each variable and how she would animate them.

**Summary**

Recording the director’s commentary for this animation revealed that Ingrid didn’t understand the square root symbol. I still gave her credit for understanding the concept of vibrating string frequency as she had understood the relevant variables correctly.
A portrait of Ryan

Ryan was a Grade 6 boy who decided to investigate the acoustics of “Stadium design”. Table 4.19 contains the transcripts of Ryan’s three videos.

Table 4.19

*Ryan’s video transcripts for “Stadium design”*

<table>
<thead>
<tr>
<th>Prior knowledge video</th>
<th>Transcript</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>My subject is stadium design, and, based on acoustics, I don’t know anything except I’m amazed how it can stand such sound and noise without you feeling it in your body.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Completed explanatory animation</th>
<th>Transcript</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>This animation is focusing on the acoustics of stadium design and not how a stadium looks. Sound can bounce back and forth in most stadiums like in this game of pong. The sound waves will eventually lose energy but there are a few simple things that can be done to reduce the sound which bounces around. Parallel surfaces are part of the problem so using different angles will help stop the sound from going back and forth. Soft surfaces will absorb much of the sound energy. This pong visualisation is good for showing where the sound moves but the air itself doesn’t actually move around as that would be wind. Sound waves travel by air molecules vibrating and passing these vibrations on. Newton’s cradle is a better example of how sound waves travel. It shows how energy is transferred through a substance without that substance having to change its position.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Director’s commentary</th>
<th>Transcript</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>When most people are thinking or they are designing a stadium, generally they’re thinking about their view that the spectator gets, not really how it sounds. I made a bit of a mistake when it showed the, the ball losing energy and it just went straight to the ground. Because I really should have shown it shrinking away because air, if it has no sound, doesn’t just fall to the ground. I think the &quot;Pong&quot; visualisation was a bit of a breakthrough for me. It enabled me to understand the subject much more than I did before. I think that was just because I was watching something happening. The &quot;Newton’s cradle&quot; was a breakthrough because it made much more sense and I understood what I was doing.</td>
</tr>
</tbody>
</table>
Introducing Ryan and his topic

Ryan played trumpet in the school orchestra so I knew him a little better than some of the other children due to our extra time and experiences together. My discussions with Ryan were often fruitful as he was very articulate and he displayed a natural sense of curiosity.

The acoustics of stadium design struck me as a particularly suitable topic for an explanatory animation. My reflection at the time was that it seemed like a “really promising topic. I like the way that it is inherently scientific, due to acoustics, and yet quite accessible as stadiums are frequented by multitudes of people” (Researcher’s reflexive journal, 22\textsuperscript{nd} June 2011). As a music teacher, I also had an interest in acoustics so I was keen to see where this animation would take us.

Creating the ZPD with Ryan

Ryan tended to work independently for much of the time during the initial project sessions. I soon learned that Ryan was expecting me to provide content knowledge for him as evidenced by his reflection after the second session, “Umm, today I didn't learn anything. I was just starting to work on my animation of my stadium” (Student reflection, 28\textsuperscript{th} July 2011). The following week I discussed ripples on a pond as a widely accepted metaphor for sound waves. Ryan appreciated this suggestion and soon incorporated ripples into his imagery as shown in Figure 4.27. “Today I learnt that ripples in a pond are a good way to describe what sound waves look like” (Student reflection, 11\textsuperscript{th} August 2011).

Figure 4.27. “Stadium design” screen shot 11\textsuperscript{th} August 2011.
The opening night of our school musical production gave me a chance to ask a professional sound engineer “about audio so I could be of further assistance to Ryan. He mentioned bass traps and reflective panels” (Researcher’s reflexive journal, 13th September 2011). The idea of a reflective panel was well received by Ryan and it was soon incorporated into his imagery as shown in Figure 4.28:

Today I had an idea of getting lots of little music notes and making a sort of pointy edged thing and bouncing them off while playing a song and showing what different angles can mean. And then show a straight line and show what a difference that would make to the sound and feel of being in a stadium (Student reflection, 22nd September 2011).

![Figure 4.28. “Stadium design” screen shot 22nd September 2011.](image)

My reflection on Ryan’s reflective panel shape gave me another idea for a possible metaphor. “This visualisation has the potential to be quite memorable and even iconic as it could resemble the early arcade game pong where a ball is bounced between paddles in a game of tennis” (Researcher reflection, 22nd September 2011).

I didn’t see Ryan again for five weeks due to an extended family holiday during the project (i.e., three Storyboard sessions and two weeks of school holidays). Towards the end of his absence, I felt that Ryan would need something tangible to work on to help him catch up with the other children. My initial suggestion involved the pong imagery. Since that moment in Session 12, Ryan made consistent and rapid progress each week as he sought to reconcile his understanding of the invisible, yet ubiquitous, nature of sound. Choosing and critiquing appropriate metaphors proved to be the turning point for Ryan’s conceptual consolidation. The learning that was facilitated
through these discussions created the ZPD for Ryan as he began to think carefully about the implications of each metaphor.

**Ryan’s conceptual journey**

During the week following Ryan’s implementation of the pong metaphor, I wondered whether I was overdoing the preparatory research in between sessions. “Am I doing too much? I have spent most of tonight researching the children's topics to be able to give them strategic guidance tomorrow. They are the ones who are supposed to be answering these questions” (Researcher’s reflexive journal, 9th November 2011). In retrospect, I have no regrets about my additional research. In Ryan’s case, my homework led to an even bigger breakthrough:

> Whilst preparing for this session, I came across some information about how sound waves involve the transmission of energy but the air itself doesn’t move, as that would be wind. The pong idea might have been short lived as it suggests that the air does move. Another metaphor that might be useful involves those toy balls that hang together on strings from a frame (I can’t remember what they’re called) (Researcher reflection, 10th November 2011).

I soon found out that the suspended balls were called “Newton’s cradle”. There was a simple animated GIF online that I was able to show to Ryan. “Brendan showed me this animation of the Newton’s cradle which I think is a good way of showing how the air doesn’t move. But the…it’s the…energy in the air that’s moving. Is that right?” (Student reflection, 17th November 2011). After transcribing Ryan’s reflection, I concluded that he understood the variables of sound, but that he wasn’t sure about how these variables affected one another.

Ryan and I had assumed that the Newton’s cradle metaphor would replace the pong imagery. Through more discussion, we came up with a better idea. “Today I decided that I’ll show the pong imagery first and then I’ll show the Newton’s cradle to show how the sound moves through the air” (Student reflection, 1st December 2011).
At the end of the last animation session, Ryan was still working on the Newton’s cradle imagery as shown in Figure 4.29.

![Figure 4.29: Screen shot of prototype Newton’s cradle.](image1)

Ryan used the curved lines on either side of the balls as provisional scaffolds to enhance the ball swing. “I’ve made a curved line so then I can show, well it will be easier for me to keep, a perfect arc for the cradle” (Student reflection, 1st December 2011). Working with Ryan also surfaced some of the most interesting dynamics around the issue of co-authorship. Ryan delegated the completion of Newton’s cradle to me during the last session as we had run out of time. Ryan’s arc in Figure 4.29 was too small so I expanded it accordingly and also took the opportunity to change some of the colours as shown in Figure 4.30.

![Figure 4.30: “Stadium design” construction imagery 10th December 2011.](image2)
Of course, the colours and improved swing didn’t affect the conceptual content of the animation. My rationale for fixing these details was due to the fact that the “Insert duplicate slide” animation technique still takes quite a lot of time as small movements must be made to the imagery prior to each enactment of this process. Getting the imagery right in the beginning is thus time well spent. I had also noted that it would have been ideal if Ryan could have been there for the final stages of the animation for his own spatial learning, which I detailed in my journal. “The circle and the horizontal line are used to ensure a smooth swing of the pendulum. They are then deleted. It’s a shame that Ryan couldn’t be here for this as it is additional learning for geometry and spatial intelligence” (Researcher’s reflexive journal, 10th December 2011).

This issue of completing some aspects of the work was raised the following week at the debriefing session. Some students were happy to receive assistance but Ryan expressed some apprehension about this:

**Brendan:** Do you feel that not being there right to the end, like some of your footage, some of the imagery you actually hadn’t made…I had to make it to fill in the gaps.

**Ryan:** I felt that maybe I would have liked to finish, because now it sort of feels like, it’s Brendan and my work so it’s not really my work anymore. And it becomes most, I had done most of the imagery, but then…then just before when we saw it, [it] makes me think, ”I didn’t even do that” so it feels a bit weird.

**Brendan:** No I agree. That would, that’s what I wanted. It’s just a case of we didn’t get, umm…we had to get it done. We had to get it finished (Debriefing session 1C, December 15th 2011).

Although Ryan was open about his preference to do all of the work himself, he had delegated this task to me in the previous session when he said, "I've told Brendan what I need to be done, so the finishing touches, and he's going to kindly help me with that" (Student reflection, 8th December 2011).

A postscript for this issue occurred over two years later when I saw Ryan at a sporting event on 26th February 2014. When asked about his preference for doing all of the imagery himself, he replied that he was surprised that he had ever expressed concerns about my collaboration in the final stage and that he was glad to have had assistance and guidance. Ryan also said that his most vivid memory of the whole project was Newton’s cradle.
At the very end of the project, I had some additional interaction with Ryan that was unscheduled. At the end of the first debriefing session, Ryan’s final director’s commentary had not been recorded, as he had to leave when the bell went at 3:30 pm. When he returned prior to lunch the next day, he was a few minutes early so I invited him to walk with me across the schoolyard, as I was responsible for taking a grade of 6 year-old children back to their classroom. During this walk I mentioned that there was an error in his completed animation where the sound loses energy but I didn’t want to tell him what it was without giving him one last chance to figure it out. Figure 4.31 depicts a ball (i.e., sound) falling when it has lost energy.

![Figure 4.31. Screen shot of falling ball.](image)

By the time we were back in the Music room and we’d watched it again, Ryan had not figured it out and was curious to know what it was. I explained that his falling ball was behaving like the wind rather than sound. Ryan discussed this insight directly in his director’s commentary:

> I made a bit of a mistake when it showed the, the ball losing energy and it just went straight to the ground. Because I really should have shown it shrinking away because air, if it has no sound, doesn’t just fall to the ground (“Stadium design” director’s commentary).

It appears that our discussion surrounding the falling ball provided the missing piece to Ryan’s conceptual puzzle. Ryan described his use of metaphors in his director’s commentary as a “breakthrough”. I think that Ryan was right to use the word *breakthrough* for both the pong and Newton’s cradle metaphors because they gave him a course of action and a context for discussion. Ryan’s case is unique in that he presented multiple metaphors and then critiqued each metaphor explicitly in his voice-
over script. Waldrip and Prain (2013) have stated that students need “to be able to explain limitations of some of their proposed 2D representations to indicate their understanding of concepts” (p. 27). Ryan’s ability to discuss the strengths and limitations of these two metaphors is a demonstration of model-based reasoning (Nersessian, 1984, 2002, 2008, 2012) and a representation construction approach to learning (Tytler, Hubber, Prain & Waldrip, 2013) where a critique of representational choices helps to guide and focus the learning. Table 4.20 is Ryan’s final conceptual consolidation rubric.

Table 4.20
Ryan’s final conceptual consolidation rubric

<table>
<thead>
<tr>
<th>Uses correct terminology</th>
<th>With assistance</th>
<th>Simplified terminology</th>
<th>Some correct terminology</th>
<th>Actual terminology</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
<tr>
<td>Identifies relationships between variables</td>
<td>Not apparent</td>
<td>With assistance</td>
<td>Basic understanding</td>
<td>Deep understanding</td>
</tr>
<tr>
<td>Self-assessment scale. Does the student think that they understand their topic?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

A retrospective content issue pertaining to the acoustics of stadium design involved contrasting open roof with closed roof stadiums. This might have been appropriate for inclusion but we didn't think of this until after the animation was completed.
A summary of Ryan’s conceptual journey is presented in Table 4.21.

Table 4.21
*Summary of Ryan’s conceptual journey*

<table>
<thead>
<tr>
<th>Ryan - Grade 6 boy</th>
<th>Prior knowledge</th>
<th>Issues or obstacles</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stadium design</strong></td>
<td>“My subject is stadium design, and, based on acoustics, I don’t know anything except I’m amazed how it can stand such sound and noise without you feeling it in your body.”</td>
<td>Ryan didn’t know where to begin until he started to consider appropriate metaphors. He described the decision to use each metaphor as a “breakthrough”.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Choice of metaphor 1</th>
<th>Choice of metaphor 2</th>
<th>Relevant variables</th>
</tr>
</thead>
</table>
| ![Diagram 1](image1.png) | ![Diagram 2](image2.png) | • Energy  
• Vibration of air molecules  
• Transmission of sound energy through air molecules  
• Changes in direction of sound energy through air molecules being reflected off hard surfaces |

<table>
<thead>
<tr>
<th>Behind the scenes</th>
<th>Different perspectives</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>The falling ball in the screen shot for “Choice of metaphor 1” is erroneous in that the ball is supposed to represent the transmission of sound energy. When sound energy has dissipated, the ball should disappear as there wouldn’t be any sound energy.</em></td>
<td>Our discussion around wind helped to clarify what sound energy is not. He included the example of wind in his voice-over script, which was also a factor in the misunderstanding about the falling ball.</td>
<td>This animation best illustrates the practice of explaining and critiquing metaphors as his critique became an explicit part of the voice-over script.</td>
</tr>
</tbody>
</table>
A portrait of Maria

Maria was a Grade 5 girl who chose to investigate “Sol Feige”. Table 4.22 contains the transcripts of Maria’s three videos.

Table 4.22
Maria’s video transcripts for “Sol Feige”

<table>
<thead>
<tr>
<th>Prior knowledge video</th>
<th>Transcript</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Diagram" /></td>
<td>I’m doing sol feige, and I know nothing about it, umm, except it’s a musical, umm, thingy and I think it includes the do, re, mi, fa, sol, la, ti, do.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Completed explanatory animation</th>
<th>Transcript</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image2" alt="Diagram" /></td>
<td>The chromatic scale has every note, which is all 12 notes. Each note is the same distance apart just like the windows on this plane. Imagine that these windows are musical notes in the chromatic scale. A semitone is from one note to the next. A whole tone is two semitones. The major scale has only 8 notes. It has the combination of whole tone, whole tone, semitone, whole tone, whole tone, whole tone, semitone. This grid shows the letter names of all 12 notes in all 12 keys. As this plane flies up and down you can see which notes belong to the scale. Many of the major scales seem complicated because of the sharps involved and yet they all sound the same. Sol feige makes this easier by using the sounds “Do re mi fa so la ti do” in any key.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Director’s commentary</th>
<th>Transcript</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image3" alt="Diagram" /></td>
<td>When I started my animation I had no idea what I was doing, like how I was going to get there or anything. Brendan helped me a lot with that so that was good. When I did the windows on the plane it made a lot more sense. So yeah, I just thought they were really clever. With the grid it made me understand a lot more ‘cause I didn’t realise there was alphabetical (order) at all. So I learnt a lot during…um, making that grid. The plane idea was really…great and how we linked to it with all the different notes and the do, re, mi, fa, sol, la, ti, do because of the plane flying up and down.</td>
</tr>
</tbody>
</table>
Introducing Maria and her topic

Maria was a very popular and confident child and she had also just landed one of the lead roles in our Circus show as the main Clown. This extraverted role suited Maria’s personality, as she was also very chatty, but never rude. Maria was also a talented singer so I thought that her choice of topic was a good match for her. She also played the piano with our school orchestra so each week I worked with Maria in her regular music class, the Storyboard project, orchestra rehearsals and the lead character production rehearsals.

I had assumed that Maria’s prior knowledge was deeper than what she stated in her prior knowledge video as she was a competent pianist and singer; “I’m doing sol feige, and I know nothing about it, umm, except it's a musical, umm, thingy and I think it includes the do, re, mi, fa, sol, la, ti, do”. Out of all of the topics that the children chose, this is the one where I could claim to have some expertise due to my role as a music teacher. My comment after the first session was that “There are many complementary concepts that inform this topic such as intervals, the major scale, accidentals and key signatures” (Researcher reflection, 21st July 2011).

Creating the ZPD with Maria

Maria was ready to abandon this topic when she attended her first session during the second week of the project. This was partly because she had been absent during the first session and she thought that the other children were too far ahead. I suspected that this was because she couldn’t visualise the imagery that she might need. “When I started my animation I had no idea what I was doing, like how I was going to get there or anything” (“Sol Feige” director’s commentary). I encouraged Maria to go and play on a keyboard for a while (with headphones on) as she was very restless and I wanted to maintain her interest. I had suggested that she could try playing the major scale in different keys and notice that the various key signatures required different numbers of black and white keys.

During the next few sessions we talked about having a grid with all 12 notes in all 12 keys. The idea was to have some sort of moveable window that could reveal the different notes as it moved up and down in front of a grid. Maria was still planning on leaving the project up until the breakthrough that occurred during Session 6. We talked about different shaped windows and referenced the long running Australian television
show “Play school”, where various shaped windows provided a lead-in to a story. It was then that I had the idea of an aeroplane with window shutters in the main cabin. As Maria had recently been on a plane when she missed the first session, she was able to clearly picture what I was suggesting. Maria immediately agreed that this would be a good way to depict the open windows that reveal various notes.

The issue of musical pitch was represented using the height (altitude) of the plane. The main feature of the metaphor was the equidistant windows within the plane and their affordance of opening and closing to reveal whatever was behind the window shutters. The windows of the plane illustrated the spatial distribution of musical pitch. Rather than having eight windows for the notes of the major scale, we decided to have thirteen semitones\(^1\) for the chromatic scale (including the octave) where every note is shown to be equidistant apart. The notes (i.e., windows) that weren’t part of the major scale could then remain closed. The open windows could then reveal both the intervallic structure of the major scale and the actual notes in each particular key signature.

It was this plane metaphor that created the ZPD for Maria. From this moment onwards, Maria was excited about her topic and ready to commence building her imagery. “The plane idea was really…great and how we linked to it with all the different notes and the do, re, mi, fa, sol, la, ti, do because of the plane flying up and down” (“Sol Feige” director’s commentary). Future discussions between Maria and myself were contextualised around the plane metaphor depicted in Figure 4.32.

![Figure 4.32. Screen shot from the “Sol Feige” animation.](image)

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\(^1\) As stated in the voice-over script, “A semitone is from one note to the next”. The diatonic [major] scale is always the same regardless of the key signature.
Maria’s conceptual journey

The value of the plane metaphor was most apparent in Maria’s grid imagery. Much of Maria’s difficulty in the early stages of creating her animation resulted from not knowing the correct order of the notes in the chromatic scale. Figure 4.33 is an early version of Maria’s grid that clearly shows that she didn’t understand the sequence of the 12 notes, which should have been A, A#, B, C, C#, D, D#, E, F, F#, G, G#.

Figure 4.33. “Sol Feige” grid imagery 1st September 2011.

Maria’s director’s commentary confirms the importance of her early attempts at building this grid. “With the grid it made me understand a lot more ‘cause I didn’t realise there was alphabetical [order] at all. So I learnt a lot during…um, making that grid” (“Sol Feige” director’s commentary).

Once the grid had been fixed, we had many other fruitful discussions as part of defining the scope of the animation. One such issue was whether the plane should ascend and descend on an angle or if it should have a horizontal orientation. It seemed logical to use angles to make the plane look more realistic and also to reflect the fact that musical notation uses height to depict pitch. We eventually decided that the animation would be easier to understand if we kept the grid (and therefore the plane) on a horizontal orientation much like a plane that has reached its chosen altitude where minor deviations in altitude are less noticeable.
Figure 4.34 is a screen shot of the abandoned, angled grid idea.

![Figure 4.34](image)

*Figure 4.34. “Sol Feige” screen shot 17th November 2011.*

Other imagery we considered in relation to how we could simulate flight included the idea of looping background imagery such as clouds (Lesson plans, 3rd November 2011). This idea came from the 2004 film *The Aviator* where some planes didn’t look like they were flying due to a uniformly blue sky. In that film, they opted to reshoot the flying sequence when it was cloudy as the clouds provided the necessary frame of reference. I liked the idea of reusing or *looping* the animation background, as this was a common animation technique. We also discussed having the grid displayed as a banner from another plane but this idea was also discarded as Maria eventually pointed out that the clouds weren’t necessary, as they would only raise the issue of “Why does the grid stay in view anyway? [when it looks like the plane is moving]” In the final version of the animation, the grid only appeared momentarily to provide the explanatory context for the metaphor by showing what was behind the open windows.

Maria had noticed during the weeks after adopting the plane metaphor that the pattern of open windows doesn’t change as the main idea behind the windows was that the intervals of the major scale are the same in every key. Focussing on identifying relevant variables also drew attention to what doesn’t change or *what was constant* (i.e., the musical intervals).
The reflexive nature of working with Maria on this animation also enhanced my own conceptual consolidation:

I thought I already understood this topic being a music teacher but I asked my wife her opinion about it, as she is a highly trained opera singer. She doesn't see it [i.e., the sol feige convention] as just helping with the major scale as it can be used for any scale including minor key signatures. I sort of knew this but I always focussed on the major scale and diatonic harmony (Researcher's reflexive journal, 20th November 2011).

I summarised this discussion when I next met with Maria and it led to the following text from her voice-over script being deleted, although many of the concepts remained:

• Sol feige is a way of using the major scale
• An interval is the distance between two notes
• The major scale is made up of whole tone and semitone intervals
• Chromatic means every (Voice-over script, 17th November 2011).

These four statements had been recorded as part of Maria’s final voice-over script. Because these deleted statements were at the very beginning of her narration, they were easily edited out without the need to re-record anything. Although this information was originally considered to be important, we eventually decided that it was a tangent. “Shortening the voice-over script by starting with the chromatic scale shows that Maria now sees Sol Feige as a naming convention and not a recipe for the major scale” (Researcher reflection, 1st December 2011). It should also be noted that Maria understood these four deleted statements or she wouldn’t have been able to decide whether they were essential or peripheral to her explanation of Sol Feige.

A final element that was discarded from Maria’s animation was the reference to black and white keys on the piano. This was so the animation could have wider musical relevance without being limited to how key signatures apply to the piano. “I’m just taking out, from my voice-over and everything, all the bits about, umm, black keys and piano and stuff so that this animation can apply to all music” (Student reflection, 20th October 2011).

We also realised towards the end of the project that it would have been quite an oversight to make an animation about Sol Feige without the viewer having the opportunity to hear the major scale. Figure 4.35 was used to conclude the animation with Maria’s voice singing the major scale as each note appeared.
Figure 4.35. Concluding screen shot from the “Sol Feige” animation.

Table 4.23 is Maria’s final conceptual consolidation rubric.

Table 4.23

**Maria’s final conceptual consolidation rubric**

<table>
<thead>
<tr>
<th>Uses correct terminology</th>
<th>With assistance</th>
<th>Simplified terminology</th>
<th>Some correct terminology</th>
<th>Actual terminology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identifies relevant variables</td>
<td>Not apparent</td>
<td>With assistance</td>
<td>Basic understanding</td>
<td>Deep understanding</td>
</tr>
<tr>
<td>Identifies relationships between variables</td>
<td>Not apparent</td>
<td>With assistance</td>
<td>Basic understanding</td>
<td>Deep understanding</td>
</tr>
<tr>
<td><strong>Self-assessment scale. Does the student think that they understand their topic?</strong></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

Of retrospective interest was a parent-teacher interview that I had with Maria’s father. His primary reason for seeing me was about Performing Arts and Maria’s role in our circus show that was being staged the following week. The evidence that I was able to show him such as the misconception about the order of the notes as seen in Maria’s grid was very clear and specific. As he was also an educator, he could fully appreciate the breakthrough that Maria was having through her participation in this project. This was the only time I had the opportunity to discuss the Storyboard project with one of the parents.
A summary of Maria’s conceptual journey is presented in Table 4.24.

Table 4.24
Summary of Maria’s conceptual journey

<table>
<thead>
<tr>
<th>Maria - Grade 5 girl</th>
<th>Prior knowledge</th>
<th>Issues or obstacles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sol Feige</td>
<td>&quot;I’m doing sol feige, and I know nothing about it, umm, except it’s a musical, umm, thingy and I think it includes the do, re, mi, fa, sol, la, ti, do.&quot;</td>
<td>On 11th August 2011, Maria was at a crossroads as she wanted to quit, thinking that her topic wasn’t very interesting.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Choice of metaphor</th>
<th>Implementing the metaphor</th>
<th>Relevant variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>AF</td>
<td>• All notes (Chromatic scale)</td>
</tr>
<tr>
<td>C</td>
<td>Ef</td>
<td>• Intervals</td>
</tr>
<tr>
<td>F</td>
<td>ff</td>
<td>• Required notes (Major scale)</td>
</tr>
<tr>
<td>G</td>
<td>f</td>
<td>• Key signatures</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Behind the scenes</th>
<th>Different perspectives</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Through assisting Maria with this animation, I began to theorise that the explanatory animation creation task can be a diagnostic tool. This insight allowed me to direct Maria towards consolidating her understanding of the sequence of the 12 notes in the chromatic scale.</td>
<td>Looking at the topic spatially was the inspiration for the aeroplane metaphor. These spatial elements were already present in the musical notation conventions as notation is an approximated graph of pitch over time.</td>
<td>The selection of an appropriate metaphor saved this project from being abandoned, and cemented Maria’s understanding of her topic.</td>
</tr>
</tbody>
</table>

Montages from the eight portraits

In summary, the data analysis can be encapsulated with three small montages\(^1\) compiled from the eight portraits. Although the ZPD generally refers to a single idea, these three montages in turn will emphasise:

1. the **zone** itself
2. student/researcher **proximity** within that zone
3. the conceptual **development** that occurred within the zone

Harriet’s portrait ["How does hair grow?"] emphasised the fact that the ZPD involves learning that is beyond the current understanding of the child. When a self-motivated and diligent child such as Harriet is involved, it can actually be more difficult to find the right questions or other stimulus to create the ZPD, as the **need for change** is often not

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\(^1\) Montage is used here figuratively to continue the portrait theme as the montages will take the form of written text.
stated by the child. Harriet’s portrait also demonstrated how a child’s understanding, in certain areas, might surpass that of the more competent helper (see Figure 4.1).

Although Sunny’s topic [“Solar cell efficiency”] was intrinsically difficult, the ZPD (or mutual ZPD) was easier to define due to the required engagement on behalf of the researcher. Working with Neil [“Satellites”] also brought proximity within the zone into focus, as he was initially highly dependent on the researcher, and then increasingly independent in pursuit of his goal.

Development within the ZPD involved careful discussions about the refinement of individual topics for both Magnus [“Electromagnetic fields”] and Molly [“Molecular naming conventions”] when their topics became increasingly specialised. For Ingrid [“Stringed instruments”], the change in topic was a complete departure from her original choice. Giving Ingrid the formula for the frequency of vibrating strings essentially defined the outer limit of her ZPD. Ingrid’s explanatory task was then a conscious path towards this boundary. Choosing an appropriate metaphor was a pivotal decision for Ryan [“Stadium design”] as the ZPD was not evident until he began to explore the affordances and limitations of the two different metaphors that he incorporated into his animation. Maria’s [“Sol feige”] progress was also dependent on choosing an appropriate metaphor. For Maria, her conceptual breakthrough surfaced the diagnostic dimension of the learning affordances evident during the construction of the aeroplane metaphor during the explanatory animation task.

These three montages illuminated aspects of the ZPD but the eight portraits also resonated with some key premises of the dual stimulation method. One premise is that the second stimulus is used as a tool to solve the first stimulus. The conceptual journey section within each child’s portrait was structured to address this issue. The unity between task and tool was further developed by Vygotsky when he stated that the dual stimulation method is “simultaneously prerequisite and product, the tool and result of study” (Vygotsky, 1978, p. 65).

Another premise is that the specific path of the resolution throughout the first stimulus (established by the second stimulus) will chronicle the formation of concepts (Vygotsky 1987). Again, the conceptual journeys within each portrait were chronological in relation to the various problem-solving events. This notion of conceptual evolution has been further developed by Daniels (2012) who noted that the historicity of development is an importantly component of the dual stimulation method. Vygotsky (1978) drew upon the writing of Blonsky (1930) when stating that “behaviour can only be
understood as the history of behaviour” (p. 65) further adding, “this idea [of historicity] is the cardinal principle of the whole [dual stimulation] method” (ibid). Vygotsky was not talking about behavior but, rather, referenced Blonsky’s thesis to explain his own developmental perspective about the nature of conceptual change.

In the current study, conceptual consolidation was also understood as a history or *chronology* of development. An affordance of the dual stimulation method was that it created both the conditions for conceptual change and also provided the means to *document* conceptual change. This was achieved through the evolving, date-based multimodal animation artefacts and the proximity afforded to me as the researcher through the ZPD.
Chapter 5. Discussion

How can one describe an explanatory animation without reference to the actual topic that comprises the subject matter? Likewise, how can one look at the conceptual ideas represented in an animation without reference to the animation itself?

The preceding statement suggests that the two components of the research question (i.e., conceptual consolidation and explanatory animation creation) are best understood in terms of how they inform one another. The same could be said for the dual stimulation method as the second stimulus (i.e., explanatory animation creation task as a tool), is best understood in terms of the effect that it has on conceptual consolidation (i.e., the task of having to explain a topic as an initial stimulus). These two issues will be re-visited for my conclusion in Chapter 6.

The purpose of the following discussion in Chapter 5 is to understand how CHAT enabled me to guide the children throughout their multifaceted task during the project. There is also more to be said about the explanatory animation design guidelines that the children used. The eight children consistently applied four design guidelines that I described as the Explanatory Animation Framework (EAF). CHAT and the EAF are presented here as a metaphorical silhouette as they were not mentioned in Chapter 4 although they were always there beneath the surface. Let us begin then by examining how the CHAT model informed the current study, and conversely, how the current study might serve the evolution of CHAT research as applied to the EAF.

**Reflections on the CHAT triangle**

CHAT, as a theoretical framework, has its genesis in Vygotsky’s notion of mediation. Wells (2011) has suggested that CHAT is an evolving framework for conceptualising research, and that “research can contribute to CHAT theory about the relationship between learning and development, as this is enacted in contemporary educational institutions” (p. 161). As discussed in Chapter 2, the unit of analysis is important when applying CHAT, as this will help determine the criterial components of the research. The current study used project collaboration (Blunden, 2009) as the unit of analysis to capture the dynamics of the evolving artefacts as seen through my proximity and interactions with the children within mutual zones of proximal development.

The mediating artefacts (i.e., explanatory animations) demonstrated many instances of incremental refinement as longitudinal development in relation to the children’s and my
co-construction of conceptual change. The storyboards in particular helped structure and sequence the children's ideas at each stage of their creation. This is significant, as the storyboards both mediated and constrained the children's conceptual learning. *Constraint* is used here in a positive sense as a design choice as information had to make it into the storyboard if it was to be included in the final animation.

The dimension of *time* within the research equation (or more precisely change over time), facilitated the analysis of project collaboration in relation to all of the CHAT components. In this sense, the CHAT model was enacted over time, or rather re-enacted. This important notion of re-enactment, through the long-term evolution of the CHAT sessions with each of the children is iconically depicted in Figure 5.1 as an extension of Engeström's third-generation CHAT model. Engeström's model is incorporated six times to symbolize a chronology of re-enacted second-generation CHAT models. These were seventeen, one-hour mediated encounters with the children occurring over five months (i.e., implicitly, the footsteps in Figure 5.1 would continue up to the number seventeen).

*Figure 5.1. CHAT sessions over time.*

The footprint analogy is to illustrate the temporal aspect of conceptual consolidation as depicted by the evolving activity systems that were co-created by each of the students.
and myself as participant research. The walking analogy in Figure 5.1 implies that change can occur in the actual meetings or in between the meetings. In the current study, the primary change variable was conceptual consolidation, which was documented and contextualised as a construct of chronology. The children’s portraits also evidenced the evolving nature of conceptual consolidation, which resonated with Engeström’s (1987) view that activity systems are open systems and Vygotsky’s (1987) insight that conceptual change develops.

The division of labour became another important part of understanding the explanatory animation task, and specifically how this related to multifaceted activity. As the children’s portraits in Chapter 4 revealed, the division of labour was often shared between the children and me. Indeed, the various tasks were conceptualised through our proximity within mutual zones of proximal development. Opportunities for meaningful interactions revolved around the children’s emerging representations available on their computer screens, stimulating discussion and critique. The children’s activity was seen to segue between different roles at various times, often within the same session as they were working on multifaceted tasks. Seven distinct activities shaped my conceptual framework of the division of labour for the children’s activity, namely:

1. Researcher
2. Graphic artist
3. Script writer
4. Narrator
5. Animator
6. Video editor
7. Pedagogical decision maker

Figure 5.2 illustrates these seven roles using a prism metaphor for the CHAT triangle.
Figure 5.2. The division of labour within the CHAT triangle.

These seven distinct yet complementary roles are described in more detail below in relation to how they evidenced examples of conceptual change:

**Researcher:** The role of researcher was a composite role that encapsulated the multifaceted nature of the explanatory animation creation task and the co-construction of meaning. The research task for both the children and me was present throughout the whole project as we sought to understand, articulate and represent the subject matter of each animation. The development of ZPD and the social construction of meaning formed an integral part of the storyboarding and animation process.

**Graphic artist:** The children used auto shapes to build their graphic imagery, but this task usually required the selection of a suitable visual metaphor. The metaphor served two roles: to identify the relevant variables that are key to the concept and to show the conceptual relationships between these variables, graphically. Without a suitable metaphor, most of the children didn’t know where to start. Bertin (1983) would have described the children’s imagery as information graphics as their function was specifically to depict “the relationships established among component or elements” (p. 415). The children clearly enjoyed the graphic construction part of their animation task the most. The graphic imagery was also the most direct window into the children’s mental models.
**Scriptwriter:** The voice-over script was the key to the explanation of each topic. I considered this to be the most important part of the animation task as it defined the content and duration of the finished animation artefact. The children didn’t share my esteem for this component and so I often had to remind the children to update their voice-over scripts throughout the project.

**Narrator:** The voice-over scripts served as a culmination of the children’s thinking. Yet, there was no conceptual change evidenced amongst the children in the recording of the voice-over scripts, as the narrations were simply readings of these scripts.

**Animator:** There is some overlap associated with the role of the animator as the development of animated sequences presupposes the creation of the initial graphics as graphic artists. For the children in the current study, they saw themselves as animators throughout the project but strictly speaking, the animator role pertained to the “Insert/Duplicate slide” process within PowerPoint. As evidenced through Neil’s portrait for his work on “Satellites”, the “Insert/Duplicate slide” process should not commence until the various key frames are completed as any errors or omissions will require the animator to create each scene again.

**Video editor:** Much of the video editing work was completed by myself, due to time constraints. This gave the children the opportunity to function as executive producers when they delegated video editing tasks to me such as the rate of various movement sequences, transitions and so on.

**Pedagogical decision maker:** Pedagogical decision making was also evident throughout the project across all of these seven tasks. The decision making task was usually done by the children but there were also instances where I made such decisions during the final video editing stage when the children were not physically present for further discussion. Such instances were carefully documented in the children’s portraits.

As illustrated here, all seven roles were evident throughout the project. It should also be noted how the transitions between these various roles occurred. There were numerous examples (such as Neil’s “Satellites” portrait), where I instructed children to focus on their voice-over script and not to spend time creating movement until the key frames were completed. Other tasks, such as video editing, involved delegation from children such as Sunny and Ryan to me, with instructions for how I should complete these tasks outside of the Storyboard sessions.
Perhaps the most important (and most common) example of pedagogical decision making, was the way the children were constantly required to determine and critique what was essential for inclusion in their representations. The digital storyboard environment allowed the children to trial such decisions as their work took the form of experimental designs. According to Gemino and Wand (2004), when working with experimental designs, “some of these variables will be manipulated while others might serve as controls” (p. 250). It was the identification of relevant variables and exclusion of peripheral variables (i.e., control variables that were constant or extraneous) that constrained the children’s conceptual and practical activity.

The following discussion about the animation genre, concluding with my proposal for a new definition of animation, is provided here as a segue into the Explanatory Animation Framework as a mediating tool, co-constructed over time.

**Animation as variant graphics**

Although animation is usually defined as a succession of moving images, there is some ambiguity when looking for a universal definition of animation. The ePotential survey for Victorian school teachers defined animation as “The optical illusion of motion created by the consecutive display of images of static elements” (http://epotential.education.vic.gov.au). Likewise, Burns and Parker (2003) have emphasised movement as the key attribute of animation with their term “kineikonic mode” (p. 59). Burns and Parker made the word kineikonic by combining the Greek words for move and image to define a genre that is distinct from the many tangents of the cinematic tradition. Gibson (1979) made a similar distinction but preferred the terms progressive picture for film and video and arrested picture for photography, as he believed that the term motion picture implies that motion has been added to a still picture. Hubscher-Younger and Narayanan (2008) have also emphasised movement within animations by defining animations as “dynamic representations” (p. 237) in contrast to static representation such as still images. All of these definitions imply that images must move rather than simply vary.

Possibly, a more inclusive term for educational purposes is variant graphics (Jacobs, 2007) where various images are viewed in succession. The word graphics is more closely associated with animation than picture or image because films are also moving images. The reason for using the word variant (i.e., changing) rather than moving is to create a definition that can also include slide shows. In a slide show, there can be movement within a frame or a complete change from one frame to another. Variant
covers both scenarios. Variant graphics retains the functionality of all of these other definitions without limitation or contradiction.

An explanatory animation is an educational animation that contains an explanation, either as narration or written text. A pedagogical example of the variant graphics definition for an explanatory animation is when key frames (i.e., frames within an animation where the image changes), are chronologically far apart. The absence of movement in such instances can actually enhance the explanatory power of the animation as the attention of the viewer can be refocused elsewhere on other elements such as the narration, or by drawing attention to a part of a static image through the use of arts elements such as colour or indexes such as arrows.

Throughout the study, completed explanatory animation is always used to differentiate the storyboards from the final animation artefacts. This might appear to be self-evident but my variant-graphics discussion asserts that the storyboards are, in fact, animations.

**EAF as a mediating tool, co-constructed over time**

The Explanatory Animation Framework (EAF) consisted of four design guidelines that I developed to guide and focus the children’s progress throughout the study. The EAF was concise enough for the children to follow and was also the result of my own experiences in creating explanatory animations (Jacobs, 2007), which had taught me that this process is both iterative and reflexive because the design would often evolve *during the creation process* rather than being predetermined.

Extant animation design guidelines such as Lowe (2001) were not directly applicable to the children in this study. This was because the development of the children’s storyboards centred on understanding the relationships between the relevant variables as the pinnacle of conceptual understanding, rather than a pre-requisite to it. Such a position is in contrast to Lowe’s (2001) guidelines that have implicit stage-gates that would become roadblocks for children who have yet to understand their topics. For example, Lowe’s second guideline, “Select the graphic entities, relationships and properties” (2001, p. 6) requires a deep and consolidated understanding of the subject matter. Mayer’s guidelines (2001) had some utility but they were increasing in number each time they were published (2005, 2009). I found that I was able to summarise and condense Mayer’s main points through more general principles such as keeping the content matter and representational choices simple.
Within the CHAT model the EAF constituted the *rules* that the children followed throughout the current study, yet these rules were fluid and co-constructed. Rules were analogous in many ways to the act of playing a game, as it is important to understand the rules for a game if one is to play autonomously. As the practitioner-researcher, I needed to explain the rules of the EAF as we went so that the rules were contextualised and personalised for each student. These rules are succinctly illustrated in Figure 5.3.

![Figure 5.3. EAF rules within the CHAT triangle.](image)

These rules were used deliberately in an attempt to keep the children focussed on the conceptual and pedagogical issues of their task. The rules within the EAF are best described as praxis because these guidelines are both practical and theoretical, established and yet open to ongoing refinement. As such, the EAF forms part of my methodology but this framework is presented here as general guidelines that could be applied to explanatory animation creation in other contexts. The four rules that comprise the EAF are summarised in Table 5.1.
Table 5.1
Explanatory Animation Framework

<table>
<thead>
<tr>
<th>Variables</th>
<th>Rules</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration</td>
<td>Keep the duration as short as possible (generally less than 2 minutes but preferably around 1 minute).</td>
</tr>
<tr>
<td>Synchronicity</td>
<td>Synchronise video (i.e., imagery) to the audio track as the narration will determine the actual duration of the animation</td>
</tr>
<tr>
<td>Focus</td>
<td>a. Avoid distractions</td>
</tr>
<tr>
<td></td>
<td>b. Maintain balance</td>
</tr>
<tr>
<td></td>
<td>c. Minimise variables</td>
</tr>
<tr>
<td>Simplicity</td>
<td>Keep the scope and sequence simple</td>
</tr>
</tbody>
</table>

The practical nature of this framework is reinforced through the fact that verbs begin each rule to describe a process that requires a series of actions and decisions. The EAF will now be expounded with additional details pertaining to both the method and rationale for creating explanatory animations in the current study.

**EAF - Duration**

The duration guidelines for explanatory animation creation were primarily for the benefit of the viewer in recognition of the limitations of cognitive capacity (Simon, 1974). Cognitive capacity is often referenced to limits on human memory proposed by Miller (1956) and Baddeley’s (1999) working memory theory but it is also a consideration of cognitive load theory (Chandler & Sweller, 1991; Sweller, 1999). Kirschner, Sweller and Clark (2006) have argued that the inquiry approach is confined by the limits of working memory:

> The onus should surely be on those who support inquiry-based instruction to explain how such a procedure circumvents the well-known limits of working memory when dealing with novel information (p. 77).
Because of the inquiry-based nature of the study, where children could choose their own topics, it was hoped that the limits of working (short-term) memory would be circumvented. The children were not receivers of information but authors of their own animations - their own knowledge construction. As these children were reflecting on and representing their ideas by creating images and writing voice-over scripts, the demands on their working memories were not excessive. In other words, the children had ample opportunities to represent their work via various multimodal options so the demands on working memory were deliberately mitigated.

Whenever I presented a child with new ideas or vocabulary (e.g., scientific concepts, animation procedures), these words were written on a separate dumping ground slide within their PowerPoint file to further avoid placing excessive demands on working memory. The tangibility of the children’s ideas developed outside of their short-term memories as these ideas were deliberately and carefully documented within their storyboards.

Although this duration guideline recommends brevity, children in the current study were never encouraged to condense an animation beyond what should be included as relevant to the topic, as that would also place excessive demands on the cognitive load of the viewer. Instead, the participants were encouraged to refine their topics knowing that other tangents could become the subject of another animation at some other time, beyond the scope of the current study.

**EAF - Synchronicity**

The eight participants worked on their imagery and voice-over text concurrently and then synchronised these elements in their final animation. Accurate synchronisation has been a requirement for multimedia best practice for many years (Vaille, 1998). Mayer refers to this as the temporal contiguity principle (Mayer, 2001; 2009). Viewers expect imagery and audio to be in sync so failure to ensure good synchronisation is an unwanted distraction (Vaille, 1998).

Voice recording was a component of all of the Storyboard animations, as the children were required to explain their topics. There are three basic methods of synchronising audio and video:
1. Pre-synced (synchronising video to audio)
2. Post-synced (synchronising audio to video)
3. Interactive (synchronising either way rather than committing to pre-synced or post-synced)

In the current study, we pre-synched as the voice-over script was recorded first and then the imagery was made to fit (i.e., sync) with it. Pre-syncing emphasised the voice-over script. This created a linear presentation and forced the author to devise the most appropriate sequence of information. Pre-syncing also ensured that the voice-over script was read with a relaxed, even delivery style rather than having to hurry through the voice-over script to keep up with the imagery.

Pre-syncing also served the purpose of prioritising the voice-over scripts as the heart of the explanations. In some instances, the voice-over scripts were amended during the recording process, as some phrases didn’t sound as smooth as we had envisioned when they were transmediated from text to speech.

**EAF - Focus**

The following three focus guidelines are nuanced variations on the same idea of maintaining clarity. These three variations are necessary because they address the structure, genre and content of an explanatory animation.

**a) Avoid distractions**

This may appear to be a common-sense and obvious guideline, yet animation can become a novelty for a new author, so they need to be reminded that any unnecessary movement is detrimental to the viewer’s ability to focus on the learning content (Rieber, 1996). Mayer (2001; 2009) refers to this as the coherence principle.

**b) Maintain balance**

A useful analogy for balance is a complex machine that is functioning properly such as a car. It is only when a car breaks down that attention is drawn to the faulty component (Callon, 1992; Latour, 1992). Hence, a well-conceived animation should also be viewed as a cohesive whole. Films provide a closer analogy for balance as a good film does not distract the viewer to focus on the process of film making by using excessive scene transitions or camera panning, zooming and so on. The relevance of these
analogies for the current study is that the basic principles of visual literacy (Kress & van Leeuwen, 2006) were important for me to understand as the researcher. Yet such principles were beyond the immediate scope of this project in terms of the extent to which these issues might be communicated to the children. As such, the word focus was sufficient to guide the children with regard to technical issues, such as distractions and balance.

c) Minimise variables

Identifying relevant variables is a basic pedagogical consideration for effective teaching. In the current study, minimising variables was not a technical consideration but a specific issue pertaining to the content knowledge of each of the children. A musical example of a minimising variable is illustrating the difference between the rhythmic feels of straight and swing by keeping all of the other variables constant (such as instrumentation, tempo, key signature and notes) and only changing the rhythm so that the rhythmic variable is the only point of difference. This emphasis on reducing variables in the children's animations could also be likened to schematic diagrams where only essential information is provided.

Another aspect of minimising variables involves the careful use of analogies and metaphors to explain topics – an aspect that will be discussed in greater detail in the next chapter. When a metaphor is used, it needs to be explained. Unless there is an explanation, the irrelevant parts of the metaphor might be inferred as being part of the comparison (Mason, 1994). This would result in the introduction of additional variables and this would actually detract from the animation.

EAF - Simplicity

Einstein is widely quoted as saying, “Make everything as simple as possible, but not simpler.” If a topic is too complicated for a full explanation, it is better to use a partial rather than simplistic explanation. A partial explanation can be extended with additional information but a simplistic explanation must be replaced to obtain further learning. A simplistic explanation is therefore unsuitable as a permanent structure for conceptual development. Simplicity is beneficial for both the level of detail in the subject matter and the choice of representations used to depict the key elements. This issue is also informed by research into perception (Marr, 1982) where the necessity for representing spatial relations raised the issue of how much can safely be left implicit.
Applying Bonini’s paradox\(^1\) to the current study would also suggest that simplicity would render the animations more effectively than excessive detail. Ockham’s razor\(^2\) is also relevant but Floridi (2011) has taken the quest for parsimony even further by formulating the “principle of economy” (p. 301) as one of the six principles of constructionism. Floridi described Ockham’s razor as a post-production revision tool, but the principle of economy is also relevant as a “pre-design planning norm. This is because revision requires the designer to be fully aware of the initial assumptions before he undertakes the investigation process and it binds the construction of any explanatory model to the conceptual resources available” (ibid). The principle of economy seeks to achieve an intrinsic alignment between explanatory models and their component parts. This alignment might exist seamlessly within the structure of the explanatory model or become explicit through reflexive enhancements such as a director’s commentary.

The four animation design guidelines presented in the EAF were used as decision-making tools to keep the children focused on the explanatory purpose of their work. They were presented as praxis because the theory behind each rule had immediate and practical implications for the animation artefacts. The EAF tool helped shape each animation into its final form. As my theoretical interest was also in the numerous decisions that the children made throughout the design process, I also incorporated the use of directors’ commentaries to help capture these decisions.

**Directors’ commentaries as a genre of research data**

Commentaries of any sort are reflexive and thus provide insights into the author’s reasoning but a review of the literature would suggest that the use of directors’ commentaries, as a genre of research data, is unique to the current study. As Bateman (2008) has suggested, there is no doubt an “entire range of semiotic modes waiting to be discovered” (p. 277) and each of them might “support particular kinds of meaning-making potential” (ibid). The directors’ commentaries not only occasioned student reflections, but they encouraged children to construct conceptual artefacts. As the children were recording reflections on a weekly basis, it was the directors’

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1 Bonini’s paradox involves the idea that the explanatory power of a model is enhanced through the omission of certain elements.

2 Ockham’s razor suggests that amongst competing hypotheses, the simplest one should be chosen, as it requires the fewest assumptions.
commentaries that required them to reflect on the project as a whole, and thus, their entire conceptual journey.

Directors’ commentaries can be both demonstrative and/or generative. An example of this was shown in Ingrid’s (“Stringed instruments”) portrait when she erroneously claimed to understand the use of the square root symbol in the frequency formula for stringed instruments. The discussion that was generated by Ingrid’s initial comment in her director’s commentary about the formula being “easy to understand” afforded further clarification and, ultimately, deeper conceptual consolidation.

Some further technical comment about directors’ commentaries might be useful here as an introduction to this genre. My initial assumption that the duration of a director’s commentary would be identical to that of the original video came from the existing practice found on some commercial movies released on DVD. In such cases, the video content is the same as that in the original film and an alternative audio track is enabled to replace the original audio track. As the current study didn’t use the DVD medium, I was not restricted to this format issue and I was therefore free to include an entirely new video file.

After the 2010 Storyboard pilot study, I concluded that the duration of the final director’s commentary should be appropriate for the content, regardless of the duration of the original video footage. The following guidelines might prove useful to other researchers for future studies:

• Directors’ commentaries might be longer than the original explanatory animation, so the video footage can be repeated, or slowed down.
• Sometimes it is appropriate to alter the original animation footage, to enhance a point being made in the director’s commentary. Such alterations might be as simple as using highlighting devices such as arrows.

1 The format issue is that a DVD has limited space. The existing practice for including directors’ commentaries on commercial DVDs involves substituting only the audio track as the video track is unchanged, and therefore, is only included once instead of twice on the disc thus saving space.
Summary

This chapter discussed the explanatory animation creation task in terms of the division of labour and then explicated four animation design guidelines as articulated in the EAF. CHAT provided a sufficiently dynamic model for understanding the complexities of both the explanatory animation creation task and evolving animation artefacts.

Chapter 6 will conclude this thesis by bringing together the findings about the children’s learning as evidenced throughout their explanatory animation creation task. These findings will then be used to suggest that the learning affordances of the explanatory animation creation animation task might be fruitful for subsequent researchers who wish to investigate conceptual change in action.
Chapter 6. Conclusion

They [the children] became software designers, and were representing knowledge, building models, and teaching concepts on their computer screens. They were thinking about their own thinking and other people's thinking - simultaneously - to facilitate their own learning (Harel & Papert, 1991, p. 45).

Introductory remarks

The data collection phase of the current study was conducted twenty years after Harel and Papert’s description of children using computers to build explanatory models as teaching artefacts. However, it should be noted that, although the technological environment has changed dramatically in the past twenty years, the actual software used in the current study has been around since Microsoft PowerPoint was released in 1990. This study was clearly not about technology but about learning. However, technology enabled the efficient construction of imagery and models to the extent that animation creation is now primarily a digital enterprise, whether it includes an explanatory role or not. Constructionism is also not about technology but about learning.

The current study was about conceptual consolidation and how this might be achieved and enhanced through the multifaceted process of explanatory animation creation. This chapter begins with three complementary theories of learning which deal specifically with conceptual consolidation. These three theories of conceptual consolidation are claims to new knowledge. The claims are tangential to the research question but are relevant as unintended outcomes of this research.

Issues more directly related to the research question are then addressed with regard to flexible models and the learning affordances of the explanatory animation artefacts. Causal links are shown to exist between explanatory animation creation and conceptual consolidation. Although many qualitative researchers generally avoid claims of causality (see Denzin & Lincoln, 2011), Maxwell (2012) believes that causation can be regarded as a “generative” process (p. 656) that conceptualises “causal explanation as fundamentally a matter of identifying the actual processes that resulted in a specific outcome in a particular context” (ibid).
Conceptual change is now widely accepted as a process (Merenluoto & Lehtinen, 2004) but generalisations about the conceptual change process cannot be applied to this study because generalisations “don’t apply to particulars” (Lincoln & Guba 1985, p. 110). The following three theories of conceptual consolidation are then deliberately situated within the current study for consideration for future studies where these constructs might be investigated as cognitive tools for conceptual consolidation.

Three complementary theories of conceptual consolidation

Three different aspects of conceptual consolidation were explored in this study. The first, entitled concepts as systems and variables, offers a definition and discussion about the meaning of ‘concept’. The second section, entitled processes of conceptual consolidation summarises the evidence resulting from each of the participants in the study. The final section, entitled paraphrase and vector-based learning, suggests a new analogy for recognising evidence of conceptual consolidation.

Because these three theories describe different phases of conceptual consolidation they are both complementary and chronological. According to Smith (1989), any claims about a theory of concepts needs to specify, “just what kind of concepts the theory is intended to apply to” (p. 60, original emphasis). Accordingly, the three theories featured here are applicable to concepts that require explanation, which are also known as explanatory concepts (Murphy, 2000; Thomas, 1977; Zif, 1983). These three theories are described below.

1. Concepts as systems and variables

In the Literature review in which this same topic was addressed, I presented literature that described the system qualities of concepts as a collective of variables. The writers cited such as Dewey (1910) and Davydov (1990) primarily described the system qualities of concepts. It should also be noted that a system could not exist without components or variables as a component is normally defined as a part of a system. The word variable was therefore the preferred term because it implies change and affords further insight when seeking to classify a variable as dependent, independent, fixed and so on.
Participants in the current study were provided with the definition that a concept is a “system containing variables”. After reading Michael Cole’s (2011) comment that “theories have a way of masquerading as definitions” (p. 49), I realised that I had inadvertently presented the children with my own theory about what a concept is. Nonetheless, definitions help establish the basis upon which theory may be elaborated. This definition functioned as a cognitive tool because it guided the children to look at their conceptual topics in a very specific way, where they consciously looked for connections between variables. The notion of a theory having practical application was proposed by the action research pioneer Kurt Lewin who said, “there is nothing more practical than a good theory” (1952, p. 169). The “system containing variables” definition became a lens for the children to determine the system qualities, or lack thereof, of their conceptual topics.

As described in Chapter 4, all but one child identified the relevant variables required to explain their topic. In the case of Harriet we didn’t realise until it was too late, so rather than using the labels of ‘choice of metaphor’ and ‘implementation of metaphor’, Harriet’s summary table used other terms, namely ‘choice of imagery’ and ‘enhanced use of text’ as seen in Table 6.1.

Table 6.1
Excerpt from Harriet’s summary table

<table>
<thead>
<tr>
<th>Choice of imagery</th>
<th>Enhanced use of text</th>
<th>Relevant variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hair texture and colour were attributes of hair rather than actual variables.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

However, in the case of all other participants in the study, the children worked at a metaphoric level, which assisted them to develop correct terminology for the variables that were relevant to their animation. A key issue is that the visual helped inform and enrich the children’s understanding of these terms and how they functioned as variables. This was because the storyboarding process was a multimodal task that encouraged synthesis leading to conceptual consolidation. Table 6.2 shows how the other children were able to identify relevant variables, which were then used to construct suitable metaphors.
Table 6.2

Excerpts of relevant variables from the children’s summary tables

<table>
<thead>
<tr>
<th>Choice of metaphor</th>
<th>Implementation of metaphor</th>
<th>Relevant variables</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Metaphor Image" /></td>
<td><img src="image2" alt="Implementation Image" /></td>
<td>• Sunlight&lt;br&gt;• Photovoltaic cells&lt;br&gt;• Current&lt;br&gt;• Voltage&lt;br&gt;• NP junctions as cohesive units&lt;br&gt;• Band gap energy</td>
</tr>
<tr>
<td><img src="image3" alt="Metaphor Image" /></td>
<td><img src="image4" alt="Implementation Image" /></td>
<td>• Straight lines (transmissions)&lt;br&gt;• Round globe (Earth)&lt;br&gt;• Transponders perpetuating signals as transmission responders.</td>
</tr>
<tr>
<td><img src="image5" alt="Metaphor Image" /></td>
<td><img src="image6" alt="Implementation Image" /></td>
<td>• Switches&lt;br&gt;• On and off&lt;br&gt;• Movement of shafts&lt;br&gt;• Transfer of energy&lt;br&gt;• Changing types of energy</td>
</tr>
<tr>
<td><img src="image7" alt="Metaphor Image" /></td>
<td><img src="image8" alt="Implementation Image" /></td>
<td>• Atoms&lt;br&gt;• Molecules&lt;br&gt;• Valency&lt;br&gt;• Hill’s law</td>
</tr>
<tr>
<td><img src="image9" alt="Metaphor Image" /></td>
<td><img src="image10" alt="Implementation Image" /></td>
<td>• Length&lt;br&gt;• Tension&lt;br&gt;• Mass&lt;br&gt;• Frequency&lt;br&gt;• Pitch</td>
</tr>
<tr>
<td><img src="image11" alt="Metaphor Image" /></td>
<td><img src="image12" alt="Implementation Image" /></td>
<td>• Energy&lt;br&gt;• Vibration of air molecules&lt;br&gt;• Transmission of sound energy through air molecules&lt;br&gt;• Changes in direction of sound energy through air molecules being reflected off hard surfaces</td>
</tr>
<tr>
<td><img src="image13" alt="Metaphor Image" /></td>
<td><img src="image14" alt="Implementation Image" /></td>
<td>• All notes (Chromatic scale)&lt;br&gt;• Intervals&lt;br&gt;• Required notes (Major scale)&lt;br&gt;• Key signatures</td>
</tr>
</tbody>
</table>
2. Processes of conceptual consolidation

The data that the children and I generated in this study displayed a striking commonality about the nature of conceptual consolidation that I had not anticipated. From my prior research (Jacobs, 2007) I was confident that the explanatory animation creation task would be beneficial for the animation author’s own understanding of their chosen topic. Extending upon this earlier work, the research question sought to uncover the specifics of how conceptual understanding is consolidated through the explanatory animation process.

The conceptual consolidation rubric (Table 3.2) proved to be more useful than originally anticipated in describing the children conceptual change over time. This rubric was revisited each week and what emerged was a consistent pattern. Progress across the rubric started with the same order of categories for all of the eight participants:

1. Each child’s growth was first evident in their use of correct terminology.
2. The discussion and adoption of correct terminology eventually led to the articulation of relevant variables.
3. Ultimately, this led to an understanding of the relationships between the variables.

This pattern is best described as a synopsis as it was clearly evident in the data. It must be noted, however, that each child’s progress was also consistent with Vygotsky’s (1978) notion of development having spiral properties where progress occurred “through the same point at each revolution, while advancing to a higher level” (p. 56). In other words, each child’s spiral was in the order of correct terminology, identifying relevant variables and then understanding the relationship between the variables, but these three criteria were not stage-gates in, and of, themselves.

As each row in the conceptual consolidation rubric contained general categories, I conceptualised that this pattern warranted restatement as a theory of conceptual consolidation. As Hewitt (2007) noted, “a theory is true to the extent that and so long as it continues to make sense of the data” (p. 241). This theory can be summarised as follows:
1. Conceptual consolidation is a complex process that can be simplified and managed by using the definition of a concept being a "system containing variables".

2. Initial research for each topic begins by first identifying, and then using, correct terminology.

3. An eventual outcome of investigating correct terminology is the identification of relevant variables.

4. The pinnacle of conceptual consolidation involves understanding the dynamic relationships that exist between the different variables.

5. Conceptual consolidation itself must be understood on a case-by-case basis because, regardless of any similarities, every concept is different.

3. Paraphrase and vector-based learning

The analogy of vector-based learning is the last in these three sequential theories. It builds upon the above statement that the pinnacle of conceptual consolidation involves understanding the dynamic relationships that exist between the different variables. The vector-based learning analogy shifts the theoretical focus onto evidence for how conceptual consolidation might be demonstrated.

In Chapter 2, conceptual consolidation was theorised as moving between the abstract and the concrete. The question “What is conceptual consolidation?” could then be rephrased as “How do you know when conceptual understanding has become concrete?” My answer to this is that a person who has a consolidated understanding of a topic has obtained sufficient perspective on that topic that it could be represented and described in multiple ways (i.e., paraphrased).

Teachers often paraphrase their content to present different perspectives on the same information to make the same point from another angle. This is because they have a consolidated understanding of their topic so that they can look at it in different ways, and personalise or contextualise the essential elements in meaningful and relevant ways. As children develop, they too learn how to paraphrase their understanding of concepts. Bruner (1966) saw early childhood as a critical period when the opportunity to paraphrase verbally with adults was a determining factor in successful learning in later life.
An analogy for how ideas can be paraphrased involves vector-based graphics as contrasted with bitmap graphics. Bitmap graphics refer to a screen being mapped out as a grid of pixels, or a page being mapped out as a grid of ink dots. Bitmap image files contain the information about where the dots or pixels go and which colours they are. Vector-based graphics contain geometric information about how and where to position the pixels or dots but they have the distinct advantage of being scalable without any loss of clarity or detail thus avoiding distortion or pixilation.

Applying this graphics-oriented analogy to the verbal language system, a *paraphrase* uses different words or a different order of words to convey the same information. The actual pixels in a bitmap image can be likened to facts as discrete units of information. By contrast, a vector image contains this same information but as a geometric *shape*.

Yet another analogy to reinforce the utility of paraphrasing is Sol Feige as a musical convention for describing melodies (as depicted by Maria’s portrait). A melody is constructed by its constituent notes. Sol Feige allows a melody to be transposed into another key, as it is the relationships between the notes that are depicted rather than the particular notes in a single key. Sol Feige, like vector graphics, retains the *shape*, which I am suggesting is more important that the particulars. Of course, the shape is constructed through the particulars but the point here is that it is recognised as a shape holistically. The vector-based learning analogy would then suggest that *concepts have a metaphorical shape* depending on the key variables and how they relate to one another. This also brings the whole concrete/abstract notion full circle, as consolidated understandings can be abstracted with full clarity, much like vector graphics.

A map analogy for giving directions to another a person to help them get to a different location might be useful here to further reinforce this notion of conceptual consolidation. If a person is able to provide another person assistance with directions, but has a limited knowledge of the area, they might only offer a single suggestion. By contrast, a local resident who is more familiar with the area would have the ability to suggest different routes and even be able to suggest alternatives such as a scenic route, or the most direct and quickest route, and so on. Again, this analogy can be likened to a *paraphrase*, where information can be readily juxtapositioned into different contexts.
Paraphrasing is also a creative act as the paraphrase itself is not predetermined. Vygotsky (1962) noted that a verbal paraphrase involves movement from word to thought, and then back from thought to different words as, “word meanings are dynamic rather than static formations” (p. 124). This link between transmediation and paraphrase is important, because, like the ability to paraphrase, only essential features need make the transition between modes.

Transmediation as a catalyst for understanding

The creation of multimodal texts in general, and explanatory animations in particular, provides a fruitful context for conceptual consolidation. This is because the resolution of the pedagogical task is a reflexive process that can help make abstract ideas concrete through the core processes of representation and transmediation across various modes. Figure 6.1 depicts this process as a catalyst for understanding.

![Diagram](image)

*Figure 6.1. Transmediation as a catalyst for understanding.*

The reason I have used a two-way arrow in Figure 6.1 is based on Vygotsky’s idea that *abstraction* and abstract thinking arises from understanding. A person’s understanding of a topic can then be linked to their ability to transmediate ideas as a cross-modal paraphrase. In the current study, the essential features that constituted the particulars of the paraphrase were the variables pertaining to each particular topic.

The focus of this conclusion chapter will now shift to the explanatory animation task and the use of storyboards.
Explanatory animation creation as a learning tool

Mental models are usually hidden. But animations that have been carefully designed to communicate conceptual topics provide digital depictions of the organisational structure of the author's logic. Fjeld et al. (2002) were amongst the first to note that mental models play an important diagnostic role, informing and improving interactions within the ZPD:

This process of turning mental activity into an object or objectification is what Leontiev called exteriorization. While it is obvious that for any individual the moment of exteriorization is an important step in his or her creative design activity, it is perhaps less obvious that this is a crucial step in making ideas accessible to others (p. 154 original emphasis).

The current study encouraged the participants to develop imagery and voice-over scripts simultaneously by creating storyboards. The representational imagery that the children constructed in their storyboards provided a digital window into their conceptual consolidation and enabled me to diagnose where students might need assistance or clarification. In this sense, the explanatory animations were not only multimodal texts but also diagnostic tools. As shown throughout the numerous examples of misunderstandings from the children's portraits, the most insightful data generated throughout this project related to areas where the children's knowledge about their concepts was incomplete or incorrect.

The learning affordances of the explanatory animation creation task can be evidenced in any modality. It is therefore not my intention to create a hierarchy amongst the various modes, as learning was evident throughout these modes at various times. An example of order was in Maria’s “Sol Feige” grid, which surfaced her misconception about the sequence of musical notes, as the construction of her grid required Maria to put the notes into the correct order. Ryan’s pong metaphor in his “Stadium design” animation surfaced the issue of movement, as he needed to differentiate wind from the transfer of sound energy. There were also examples where the terminology in the voice-over scripts provided fruitful contexts for discussion such as Sunny’s NP junction where we devised a graphical metaphor to emphasise the notion of a gap by stretching the words ‘band gap energy’ in his “Solar cell efficiency” animation. Neil’s “Satellites” animation also utilised on-screen text for his transponder portmanteau where the words ‘transmitter’ and ‘responder’ were morphed together. It should be noted that these four examples were all visual. Figure 6.2 uses the CHAT triangle as a prism to identify some of the modalities that were evident within the children’s storyboards.
The process of explanatory animation creation yielded a context for conceptual consolidation on a case-by-case basis. Much of the actual growth came from discussions with me as the teacher. As noted by Ford and Forman (2006), the teacher’s role in instruction is central because “without the constraints and guidance that the teacher provides, students would not encounter focused workable issues or engage experimental practices to address them” (p. 144).

The co-construction of meaning through my own participation in the children’s work afforded me a privileged insider position that was conceptualised as mutual zones of proximal development. This enhanced the diagnostic potential of our collaboration, as I was literally involved in each conceptual scenario. It also afforded me both insight and clarity to witness the children’s thinking in progress, and confirm that all eight of the participants developed deeper understandings of their chosen topics.

The creation of each explanatory animation required the children to represent and re-represent their topic through the process of transmediation. This transmediation process both concretised (Wilensky, 1991) the children’s mental models and made them visible for critique and discussion. The children also learnt to look at their topics from several different angles as they sought to paraphrase their topics through the selection and critique of suitable metaphors.
Explanatory animation creation was enacted in a process of dual stimulation to facilitate conceptual consolidation. The explanatory animation creation task was initially the object of activity but the project itself became the unit of analysis. In the final analysis of the whole project, the task of explanatory animation creation functioned as a transmediating tool for cross-modal cognition.

**Digital storyboards as flexible models**

The dual stimulation method was used in the current study to harness the intrinsic unity between explaining a topic (as an initial stimulus) and using the explanatory animation creation process as a mediating tool to do so (as the second stimulus). Each child’s storyboard was shown to be both a mediating multimodal artefact and a cognitive tool at various times. This would suggest that tool and artefact can merge into one but it appears that *convergence* is a more accurate way to describe this dynamic. As Garton (1993) has noted, “representation and concept formation are regarded as fundamental to mental organisation and systemisation” (p. 264). The result of applying the dual stimulation method was that the explanatory animation creation task provided a multimodal chronology of the children’s conceptual consolidation.

When the author of an explanatory animation is attempting to represent their conceptual understanding, their mental models are given tangible expression through the words, images, sounds and movements that are used to construct the animation. This does not automatically lead to conceptual consolidation but it does provide a privileged level of insight into what the author of an animation is actually thinking. In the current study, explanatory animation creation and conceptual consolidation were seen as complementary processes with the evolving storyboards functioning as semiotic mediating tools.

The evolving storyboards became mediating tools between each child and their conceptual understanding, but these same storyboards also provided a mediating role between each child and me. My interactions with the children were not unlike regular classroom interactions, where I was available for assistance as required. In this information era, Drotner (2008) sees the teacher’s role as more important than ever and she encourages educators to embrace the transition from information authority into knowledge facilitator. Knowing when to intervene is an issue that confronts teachers on a daily basis. Intervention, for researchers however, is a continuum on which the researcher must tread consciously. Wells (2007) discussed this issue as one common
to both teachers and researchers where a “Vygotskian interpretation of the dual roles of the teacher as planner of appropriately challenging activities and provider of assistance in students’ zones of proximal development” are merged (p. 266).

Explanatory animation creation is primarily a pedagogical design process. As such, incremental refinements are anticipated throughout the animation creation process and are easily implemented due to the digital nature of the unfolding representations. Sullivan (2005) captures this dynamic well with his term create to critique. The intended contrast here goes beyond a dichotomy between process (storyboard technique) and product (completed animation). The actual storyboards, which the participants in the current study constructed, were more like the prototypes that Resnick (2007) has referred to:

We never expect to get things right on the first try. We are constantly critiquing, adjusting, modifying, revising. The ability to develop rapid prototypes is critically important in this process. We find that storyboards are not enough; we want functioning prototypes (p. 5).

The terms “functioning prototype” (Resnick, 2007), “flexible models” (Clement, 2008) and “mental models” (Mayer, 1993; Rapp, 2007) are not synonymous, but, in this current study, they converged at various times. Unlike most art and design, where gradual transformations produce the finished artefact, the component parts of the children's animations were physically distinct from the completed work, as the PowerPoint files were routinely duplicated as new date-based files. As such, they provided a digital trail leading to the finished artefacts.

Jonassen (2008) has noted the link between conceptual models and learning and how this connection “provides rich research opportunities in the effects of knowledge representation on conceptual change” (p. 690). The current study seized this opportunity by capturing tangible, mental models of the author's thinking as animation creation has evolved from a hand-drawn art form into a primarily digital process. Digital art forms have one important affordance over tangible mediums such as paper, in that they can be easily edited and also reproduced which helps enhance creativity as revisions are easy to make. The digital domain also facilitated experimentation, as changes were reversible. My claim here is that explanatory animations and storyboards, at any stage of development or completion, are also “flexible models” (Clement, 2008, p. 417).
Could similar learning outcomes have been achieved by the participants in the current study if they had been using a medium other than animation? It would seem not. The explanatory animation creation process provided two additional benefits over more common or traditional tasks, such as designing a PowerPoint presentation, in the following two ways:

1. The process was sufficiently engaging and complex to sustain the project for the whole seventeen weeks.
2. The insight into the children’s mental models, which was so readily apparent through this process, provided opportunities for researcher input and diagnosis because the children needed and sought assistance due to the complexity of their task.

I would now like to change the tone of this thesis by presenting some final thoughts on this research as a *coda* (i.e., a musical term for ‘ending’).

**Coda**

This final section is presented as three *encores* to continue the musical analogy. It is common for a concert to include at least one encore for which an artist has reserved one or more of their best songs to ensure that the audience is satisfied. Indeed, an artist would be disappointed if the audience didn’t call them back out if they had reserved such material. This first encore is a summary of what I did as depicted in Figure 6.3 which presents an application of CHAT as a synthesis model.

The second encore is about things that I would have done differently if I had the chance. I have structured this second encore so that it might prove useful for anyone who wishes to build on this research in the future.

The third and final encore involves a discussion around digital artefacts including digital theses. These issues could have safely been omitted without compromising the current study and so this third encore is a risky enterprise. The performers returning to the stage for a third time might be further pushing their collective luck if they present new, unfamiliar material (i.e., issues that haven’t been raised in this thesis thus far). In spite of this risk, the affordance of digital theses might also prove useful for future researchers who are working with multimodal data sources. Let us begin with the first encore, which involves a synthesis of the children’s learning as conceptualised and enacted through an expanded CHAT model.
Application of CHAT as a synthesis model

The semiotic tool of explanatory animation creation helped the children conceptualise and communicate their understanding in powerful and complex ways that might not have been possible in more traditional forms of meaning-making. This is due to the ways that the modes enriched and informed understanding as that which was abstract or concrete in one mode might have been different in another mode. ‘Seeing’ through multiple ‘lenses’ or modes of understanding took the children (and me) to a higher plane. This is what Vygotsky (1978) referred to as children standing “a head taller” (p. 102). In other words, their understanding became deeper and more complex and they could demonstrate their sophisticated conceptual understanding at a higher level than one might expect for their developmental ‘level’.

Figure 6.3 is a synthesis model containing the main ideas from Figures 5.2, 5.3 and 6.2. Figure 6.3 brings together these three CHAT components into one to revisit three key aspects of this thesis in the three areas of:

- Rules (the inherent processes of the animation tasks and the procedures the children undertook).
- Division of labour (the ways in which the children engaged with the meaning-making process that made the learning so powerful and sustained their engagement at a deep level for a long period).
- Object (the multimodal components that made up the whole).
Figure 6.3. Application of CHAT as a synthesis model.

Figure 6.3 seeks to present the multifaceted nature of the children’s explanatory animation task as having an intrinsic unity where one aspect could not be separated from the other aspects without destroying the unified meaning. Figure 6.3 also takes the dynamics of explanatory animation creation ‘beyond Mayer’ as it explicitly links design with learning whilst still giving full consideration to activity through the division of labour. This is largely because the focus of this research enabled the child participants to become the creators of the explanatory animations rather than the viewers. It was also due to the way in which they were making animations for the sake of their own learning.

Implications for future research

I believe that the methodology devised in the current study could be implemented as is to uncover additional perspectives on multimodal learning as it provided sufficient opportunities for deep and prolonged engagement with the participants. I do, however, have a suggestion for future researchers that involves amending the methodology to
involve a group of participants to create a single animation, rather than having each participant making their own animation. The utility of the explanatory animation creation process could then be applied as a project for group work to research collaboration and to further understand the role of community within the CHAT triangle.

My suggestion for how to approach this would be to have each participant take responsibility for animating one scene. For example, a group of six participants could animate their own scene and then record their own director’s commentary. (Most of the children in the current study required around six sentences in their voice-over script to adequately convey the explanation of their topic). This would result in seven artefacts for that group (i.e., collective explanatory animation plus six different directors’ commentaries). Of course, a smaller group of three could have the participants animate two scenes each. The decision-making process around the delegation of each scene could provide rich research opportunities in addition to the learning affordances already identified for the explanatory animation creation process.

A single teacher or researcher could conceivably run an entire class this way where each of the children is in an animation group of, say, five groups of five. A small group of researchers could also structure a classroom in this manner.

It also might be interesting to use screen capture technology (such as Camtasia) throughout the animation sessions. The researcher would not necessarily need to watch all of this footage but, in instances where children experienced breakthroughs, this footage would then be available to provide more insight into each child’s creative process as it unfolded. This last suggestion is also a reminder that there are a whole range of technological enhancements that could be used to further augment multimodal research using digital artefacts.

**Affordances of digital artefacts**

I am writing these final words from the beautiful Fondren Library located within Rice University in Houston Texas. From my elevated table on the second floor I can see down to the thousands of books that line the shelves below. Of the hundreds of students in the library today, I haven’t seen any of them go anywhere near these books as everyone is on a computer. Is this another books are dead observation? Certainly not! Of course many of the students are accessing these same books and other media
from the convenience of their tables. Writing books was never about paper but, rather, the ideas and stories that are contained therein.

The current study was a multimodal undertaking. Brooks (2002) noted the affordances of directly embedding digital data in a hypermedia document (i.e., web page):

> By allowing the viewers access to some of the source data, they are offered the possibility of closely examining original data. Such transparency and reflexivity establishes a strong foundation upon which an informed discussion in relation to both the artefacts and their analyses can take place.

Brooke’s quote inadvertently raises the citation issues for electronic resources. The quote is from 2002 but there were no page numbers available amongst the various sections of her *hybrid thesis*. A hybrid thesis is where a hard copy manuscript is supplemented with a disc and/or a web presence. The American Psychological Association has guidelines for referencing web sites (as described in APA 6th) to include the paragraph number where pages numbers are not available. Citation issues might improve when a digital thesis author publishes their work on a dedicated web site using logical naming conventions such as www.nameofthesis/chaptername. Embedding paragraph numbers might also be helpful to save people the trouble of counting them up individually. Including these numbers could be likened to the verse numbers that have been arbitrarily added to biblical texts to assist referencing.

Beyond these somewhat mechanical citation issues is the issue of how to navigate through a hypertext document. Dicks, Mason, Coffey and Atkinson (2005) have expressed concerns about people getting lost in a seemingly endless chain of links:

> Hypertext opens up the text through multiple linking, allowing the reader the opportunity to generate unpredictable reading paths. Given this, how does an author, especially one dealing with academic argumentation, simultaneously orientate a reader towards intended readings as well as allow a reader to discover his or her own pathways through the hypertext? (p. 64).

Definitions of hypertext as being ‘non-linear’ are problematic as readers can still be encouraged to follow the same linear path in spite of the options that they are presented with. Of course, books have always had this affordance too as people are free to turn to any page and indeed, some books such as text books are specifically designed to encourage this.

Perhaps we have not adequately considered the genre with which multimodality might be presented. In Bateman’s (2008) book *Multimodality and genre: A foundation for*
analysis, he chose to focus on static artefacts also known as “multimodal documents” (p. 9). The exclusion of animation in Bateman’s book was because of his assumption that there was already sufficient complexity in static artefacts and that we must “learn to walk before we can run” (ibid). In other words, the added variable of movement was considered to be problematic for interpreting and analysing multimodal documents. Although Bateman is correct in asserting that our understanding of multimodality is informed by understanding of the various modes, I would suggest that animation does not belong in the too hard basket or we might never make this transition.

Dicks et al. (2005) also noted that the publication of a multimodal thesis is an issue for Universities that has not been adequately considered. Accordingly, they suggest that “perhaps the biggest obstacle to academic hypermedia authoring is likely to be academic institutions” (p. 67). I would like to propose that until such time as purely digital theses are commonplace, the current hybrid format should be reversed where print options are linked as PDFs from the web pages rather than having hard copies augmented by web pages and/or discs.

The current hybrid approach is a compromise for both the reader and the author. For the reader it is inconvenient not to have the relevant media embedded at the point of discussion. For the author, the hybrid approach fails to recognise that the navigational structure of a digital thesis can also function as a map of intention as the architecture of a hypermedia framework reveals and even reinforces the author's thinking (Chen & Dwyer, 2003; Jonassen, 1988; Kearsley, 1988). Embedding PDF files would then be a step in the right direction as the multimodal affordances of the digital medium would not be restricted whilst still allowing access to hard copy text. As Moss (2008) noted:

How do we take up the potential of new data sources and their analytic representations? These issues are critical to understanding how we might craft original questions but also how we might develop the textual forms of ‘writing up’ research (p. 232).

My rationale for wanting to construct a digital thesis using hypermedia is an acknowledgement and respect for the digital nature of the data generated by the eight Storyboard participants, giving full recognition to the richness of multimodality. In no way am I suggesting that videos or images should replace written text as written text can actually enhance the functionality of other media such as audio and video. For example, it would have been easier to have left the spoken words from the children's reflections as audio files but, instead, they were also transcribed for closer analysis.
The current study was a purely digital thesis (i.e., web page) from its conception in 2008 up until 2013. During this time I sought to tread cautiously within the hypertext environment by retaining formal academic structures using traditional chapter headings. In 2013 it became clear that it would be easier for my supervisors to provide feedback to me if they had written text in chapters rather than a web page. Transferring the web page sections into a single Word document in 2013 however did have some affordances of its own. It wasn’t until I transferred the various sections of written text into a single, linear Word document that I was able to get a sense of where content was unintentionally repeated and what the overall structure of the argument was. If I was to start again in 2015 I would plan to enable online comments using a wiki (i.e., a web application that allows people to add, modify or delete content in collaboration with others) with restricted access to the site using password protection during the various draft stages.

Perhaps all of these issues are best understood in terms of using the most appropriate medium for the content. I will conclude this discussion by reiterating some examples of digital affordances from the current study. In other words, what elements within this thesis are unique to the digital medium?

1. The children’s explanatory animation creation task was intrinsically multimodal as they were simultaneously dealing with various modes.
2. The inclusion of the all of the children’s data through the links to their PowerPoint files in the Weekly reviews would not have been possible on paper due to the restriction of space.
3. Likewise, digital appendices such as the Researcher’s reflexive journal would not have been practical to have included as a paper appendix as this would have constituted an additional 40,000 words.
4. The children's imagery was qualitatively different from their text and so these images had to be handled differently. If words were used to describe the imagery without actually showing the imagery then it would force the reader to vicariously generate their own mental representations which would invariably be different from the children's own art.

In addition to multimodality, perhaps the most important part of the current study was that the children became teachers to enhance their own learning. The concept of learning by teaching, however, has been around for thousands of years. Papert (1991) saw the potential of technology to enhance this practice:
‘Learning by doing’ is an old enough idea, but until recently the narrowness of range of the possible doings severely restricted the implementation of the idea. The educational vocation of the new technology is to remove these restrictions (p. 22).

Education and schooling have a long tradition of embracing technology, but often to use new technology to do the same old things with these new tools. If we truly embrace the semiotic affordances of multimodality, we should also embrace the various mediums which support these modes, and more importantly, seize opportunities to create new multimodal artefacts.

The dual stimulation method can also provide powerful opportunities for learning using digital technologies. Sannino (2014) has described dual stimulation as both a method and a principle with the principle being a “path to volitional action” (p. 1). Other commentaries on Vygotsky’s work such as Engeström (2011) and Valsiner (1988) point to a further expansion of dual stimulation to give “freedom to participants to construct the task itself, not only the means to solve it” (Sannino, 2014, p. 6). The explanatory task, which is ubiquitous in schools of all descriptions, could then be likened to the first stimulus of the dual stimulation method. Creating a whole range of second stimuli based on the affordances of both technology and multimodality could then enrich the learning process in ways that were not previously possible.
References


http://dx.doi.org/10.1080/0305569940200209


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Appendix A - CD-ROM of the Storyboard website

The following instructions are related to accessing the content on this disc:

1. **Insert disc into CD/DVD drive.** This content will work on both PC and Mac platforms and various operating systems. The content can either be viewed directly off the disc or by copying it onto the computer's hard drive.

2. **All of the content on the disc is in the one folder called “Storyboard”.** All of the content can be accessed once the index.htm file has been located and opened. Locate this file by opening the “Storyboard” folder and then look for it alphabetically (depending on your default file display options). **Launch your web browser by simply clicking on the index.html file.**

N.B. Some computer settings restrict access to multimedia when viewing content from a hard drive or disc. Any such issues can be avoided by viewing this content online at www.brendanpauljacobs.com
Appendix B – Plain language statement

Plain Language Statement

Storyboard: Primary school students designing and making explanatory animations

In what ways can storyboarding and animation creation enable primary school students to articulate and consolidate their conceptual understanding?

Your child is invited to participate in the above research project, which is being conducted by Mr Brendan Jacobs (PhD student), Dr Tony Jones (responsible supervisor) and Dr Nick Reynolds (co-supervisor) of the Graduate School of Education at The University of Melbourne. This project will form part of Mr Jacob’s PhD thesis, and has been approved by the Human Research Ethics Committee and the Department of Education and Early Childhood Development (DEECD).

Procedures/risks

The primary focus of this research project is conceptual consolidation and how the children’s understanding of their chosen topics evolves during the process of representation through animation. Working in a digital medium is an efficient way to achieve these objectives as work can be modified without having to start again. It also allows children to present different versions of their work for comparison and immediate feedback.

A unique genre of data arising from this study is the director’s commentary audio recordings made on a weekly basis where each student discusses their progress and future directions for learning.

Working on computers in this manner is unlikely to cause discomfort or inconvenience to any child so it has been classified as a “Minimal risk” project by the University of Melbourne. The teacher immediately responsible for your child’s progress is Brendan Jacobs and, as always, the focus will be on their wellbeing and educational development.

Data creation

The Storyboard project utilises multimedia extensively. Children create text, graphics, audio, photographs, videos and animations. The students will retain ownership of their work at all times.

Data collection

The children store their data on the Elwood Primary School computer network and are also able to take work home if they choose to work on it at home. It is customary with PhD research projects to destroy data after a period of 5 years. As there is nothing inherently confidential about the data and it belongs to the children, there appears to be no reason to destroy it at any time.
Right to withdraw

Please be advised that your participation in this study is completely voluntary. Should you wish to withdraw at any stage, or to withdraw any unprocessed data you have supplied, you are free to do so without prejudice.

Participation

If you would like to participate, please indicate that you have read and understood this information by signing the accompanying consent form and returning it to school. We will protect the anonymity and confidentiality of your child to the fullest possible extent, within the limits of the law.

Should you require any further information, or have any concerns, please do not hesitate to contact any of the researchers; Brendan Jacobs (W): 9531 2762, Tony Jones (W): 8344 8524 or Nick Reynolds (W): 8344 8526. If you have any concerns regarding the conduct of the project, which you do not wish to discuss with the research team, you can contact:

The Executive Officer, Human Research Ethics, University of Melbourne, VIC 3010. (W): 8344 2073.

Summary for children

The Human Ethics Advisory Group at the University of Melbourne has requested that an additional Plain Language Statement be provided for the children. The process of distributing the forms that you’ve received about the Storyboard project involved the following statement being read to your child to ensure a shared understanding of the project:

- Brendan is interested in the work that can you do on computers.
- He’d like to include your best work for a project he’s doing at the University of Melbourne called Storyboard.
- If you want Brendan to include your work in his project then you and your parents need to return a permission form.
- Any other people outside of Elwood Primary School who see your work will know what Grade level you are in and whether you are a boy or a girl but they won’t be told what your name is.

This plain language statement is for you to keep.
Appendix C – Consent form

Melbourne Graduate School of Education

Consent form for persons participating in a research project

Storyboard: Primary school students designing and making explanatory animations

In what ways can storyboarding and animation creation enable primary school students to articulate and consolidate their conceptual understanding?

Names of researchers: Brendan Jacobs (Elwood Primary School), Dr Tony Jones (University of Melbourne), Dr Nick Reynolds (University of Melbourne).

1. I consent to participate in this project, the details of which have been explained to me, and I have been provided with a written plain language statement to keep.

2. I understand that my participation may involve samples of my child’s multimedia work (i.e. text, audio, video, photographs and animations), being submitted with the Storyboard PhD thesis, being published electronically at www.brendanpauljacobs.com and possibly being published in journal articles or used in presentations within the educational community.

3. I acknowledge that:

   (a) I have been informed that I am free to withdraw from the project at any time without explanation or prejudice and to withdraw any unprocessed data I have provided;

   (b) I have been informed that the confidentiality of my child’s identity will be safeguarded subject to any legal requirements.

If you consent to your child’s work being included in this study, please return this completed consent form to Brendan before the scheduled commencement date of 21st July 2011.

Name of participant (student):

Parent’s signature: ___________________________ Date: ___________________________

Student’s signature: ___________________________ Date: ___________________________
## Appendix D - Attendance roll

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Appendix E - Lesson plans for the 2011 case study

Session 1   21st July 2011

Objectives / teaching points / recommendations:

- Introduction to the task of explanatory animation creation. (The Explanatory Animation Framework was not discussed as that would have been too much information at this early stage).
- File saving conventions. (i.e. concept name with date suffix).
- Introduction to PowerPoint “Insert duplicate slide” function to create various slides.
- Time set aside for recording prior knowledge videos.

Absent: Maria.

Researcher reflection: The students were very attentive during the initial focus session. I was careful not to talk for too long as the children wanted to get started as soon as possible.

I must not have explained the voice-over script clearly as many of the children thought that the voice-over script was simply a transcript of their prior knowledge video.

Session 2   28th July 2011

Objectives / teaching points / recommendations:

- Distinguishing between the director’s commentary genre and that of the voice-over script.
- Reminder to children that they do not need to ask me for permission for their ideas or plans as this project seeks to track the decisions and progress that they make. (This might seem obvious but there were several such questions during the first session).

Absent: Ingrid.
**Researcher reflection:** During the first session I had spread the children out as much as possible including the two smaller rooms off to the side of the Music Room. This was because the 2010 class was very chatty. The 2011 class is only half the size and the children seem to be much more productive. I now have them in the same big room so that they can hear the interactions that I have with the other children. These discussions could be seen as a distraction but I believe they can be a catalyst for the children to look at their own topics from different angles and perspectives.

**Session 3  11th August 2011**

**Objectives / teaching points / recommendations:**

- Demo of student work from Storyboard web site. (This is a gentle reminder to the group that their work is being published. The main area I would like to see improvement in is their voice-over scripts as these should be in the 3rd person).
- Additional reminder about the distinction between voice-over script and student reflections.
- Introduction to concept maps.

**Researcher reflection:** The children already knew about concept maps.

**Session 4  18th August 2011**

**Objectives / teaching points / recommendations:**

- Demonstrate the *reverse engineering* approach to graphics. This involves drawing an image with the required detail and then erasing parts and saving each version as separate images. There are three benefits from using this technique:
1. It is faster to erase than it is to draw.
2. Sufficient detail is included in the first instance. The alternative to this is where a student decides that they need to add more detail and then have to add it to every slide.
3. The stability of the image is maintained as there is no risk of the position of objects being moved unintentionally.

**Researcher reflection:** Only five out of the eight children recorded student reflections as we ran out of time. In future, directors’ commentaries could commence being recorded any time after the teaching focus has concluded.

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**Session 5  25th August 2011**

**Objectives / teaching points / recommendations:**

- Review file saving conventions
- Explain macroconcepts
- Discuss representations

**Researcher reflection:** During this session I promised the children who didn’t have internet access that I would arrange different computers for them from now on.

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**Session 6  1st September 2011**

**Objectives / teaching points / recommendations:**

- Reiterate my definition of a concept being a system containing at least one variable.
- Explain paraphrasing.

**Researcher reflection:** I see similarities between concepts and paraphrasing in that they both identify key information.

None of the children knew about paraphrasing but they seemed to pick it up quickly. I used comedy as an example where comedians twist or invert some point in a story for comedic effect. My specific example was from twenty minutes before the session.
when a colleague asked me in the staffroom; “How many sleeps until the Circus show?” (that I’m working on for our annual production). The real answer would have been twelve but I replied “None”.

After the session I concluded that the specific advice or feedback I have for each student should be shared during the focus session in front of the class. This would be beneficial for four reasons:

1. I can’t forget or run out of time.
2. These instructions have some relevance to the other students.
3. I can proceed immediately with recording the student reflections as each participant would have already received individual feedback.
4. These recordings always take longer than I think.

Session 7  8th September 2011

Objectives / teaching points / recommendations:

• Explain and proceed with a new lesson structure where my feedback is given during the initial focus session as follows:
  • “Cell duplication” - Investigate chromosomes. Discuss transitional imagery.
  • “Chemical reactions” - Decide on whether to specialise and refine the topic.
  • “Electromagnetic fields” - How do the LCDs work?
  • “How does hair grow?” – Suggest making cross-sectional, close-up imagery.
  • “Satellites” - How many satellites are needed to transmit a signal around the world?
  • “Sol Feige” - Fix the grid.
  • “Solar panels” - View other animations about how photovoltaic cells work.
  • “Stadium design” – Should we include soundproofing recommendations for existing stadiums or continue to focus on constructing new stadiums?

Researcher reflection: Providing feedback to each student during the focus session was a definite improvement. I will continue to start each session in this manner.
Session 8  22nd September 2011

Objectives / teaching points / recommendations:

- “Cell duplication” - Consolidate chromosomes.
- “Chemical bonds” - Mention molecules and suggest “Molecules” or “Molecular chemistry” as a title.
- “How does hair grow?” - Commence cross-sectional imagery.
- “Satellites” - Continue investigation of the question about the number of satellites required for a global transmission.
- “Stadium design” - Mention bass traps and reflective panels.

Absent: Magnus, Molly, Sunny, Maria.

Researcher reflection: I had anticipated that the three Grade 5 students would be absent due to the Grade 5 camp. Molly was also absent leaving only 4 out of 8 students. This was actually beneficial in terms of providing me with more time to spend with the remaining students. I had a very long interaction with Ingrid. I had thought that this student was almost ready for the final construction of her imagery once chromosomes had been investigated a little further. We came across a cell duplication animation at http://www.cellsalive.com/mitosis.htm. This animation was very effective as it also contained video of actual microscopic cells duplicating. The various phases of cell duplication could also be viewed separately to reduce cognitive load.

Once we had viewed this animation, there appeared to be only three options open to us:

1. Recreate a similar animation using the new details we had learned.
2. Simplify the animation to make it easier to explain.

Recreating the animation was not appealing as it would have been a lot of work with little reward considering that her representational ideas would have been derivative. Simplifying the animation grated against my pedagogical ideals stated so succinctly by Einstein when he said “Make everything as simple as possible but not simpler.”

This left us with only one option and that was to start a new topic. I reassured Ingrid with the fact that a 2010 Storyboard participant had successfully changed topics
even further into the project. I also mentioned that seven out of the eight topics for the current project were scientific so it would be good to have more variety. She then proposed that we do something musical and “Stringed instruments” was soon chosen. (This new topic is actually scientific, mathematical and musical).

Session 9  14th October 2011

Objectives / teaching points / recommendations:

- “Electromagnetic fields” - Suggest an electric motor as a suitable visualisation instead of LCD screens.
- “How does hair grow?” - Commence cross-sectional imagery of the actual hair shaft.
- “Satellites” - Reminder that transmission signals travel in straight lines.
- “Solar panels” - Encourage Sunny to identify the various layers in a solar panel.
- “Sol feige” - Discuss making the grid angled with ascending and descending pitches.
- “Stringed instruments” - Share the formula for determining frequency and discuss animating the formula.

Absent: Molly, Ryan.

Researcher reflection: This was a Friday session instead of our regular Thursday due to “Planning week”. It was nice to be able to write these reflections immediately after the Storyboard session instead of immediately transitioning to leading a rehearsal with our School Orchestra after our usual Thursday time.

Session 10  20th October 2011

Objectives / teaching points / recommendations:

- Discuss the animation terms “tweening” and “keyframes”.
- Remind students that we will be syncing video to audio so they should remember to focus on their voice-over scripts.
- “Chemical bonds” - Suggest that just covering the naming of molecules might be a more manageable topic.
• “Electromagnetic fields” - Confirm the essential elements of an electric motor. Discuss the option of renaming his title to “Electric motors”.
• “How does hair grow?” - Continue cross-sectional imagery of the actual hair shaft.
• “Satellites” - Remove references to satellites that are communicating with each other because they are not configured properly or are not part of the same network.
• “Solar panels” - Suggest that the handful of layers that belong in a solar panel are not merely shown and explained but, rather, explained as they are successively added. In this manner the animation would literally build a solar panel.
• “Sol feige” - Discuss black and white notes and how they have no relevance to major and minor keys.
• “Stringed instruments” - Commence voice-over script to determine the order of the variables.

Absent: Ryan.

Researcher reflection: The individual feedback that I had prepared for each participant was more detailed than usual for this session. This led to a return to the earlier approach where individual advice and recommendations are given individually rather than during the initial focus time.

Session 11  27th October 2011

Objectives / teaching points / recommendations:

• “Stringed instruments” – Suggest that Ingrid uses my laptop from now as it is better than the desktop computer that she been using.

Absent: Harriet, Neil, Maria, Ryan.

Researcher reflection: A class size of three or four is ideal.
Session 12   3rd November 2011

Objectives / teaching points / recommendations:

• “Electromagnetic fields” - Define the scope of the animation.
• “Molecular naming conventions” - Complete conventions.
• “Satellites” - Discuss “Fat Jeffery” in terms of the problem of straight lines and a round globe.
• “Sol feige” - Complete voice-over script so we can commence generating appropriate imagery. Discuss how we could simulate flight (looping background imagery such as clouds).
• “Stadium design” - Pong game visualisation idea.

Absent: Harriet.

Researcher reflection: Today I shared how the eight mini case studies fit together as an additional research story:

<table>
<thead>
<tr>
<th>Topic</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>How does hair grow?</td>
<td>Concepts definition</td>
</tr>
<tr>
<td>Molecular naming conventions</td>
<td>Naming is arbitrary. Representation is functional</td>
</tr>
<tr>
<td>Stadium design</td>
<td>Scope and sequence</td>
</tr>
<tr>
<td>Satellites</td>
<td>Eliminate non-essentials</td>
</tr>
<tr>
<td>Electromagnetic fields</td>
<td>Gestalt theory</td>
</tr>
<tr>
<td>Solar panels</td>
<td>Building the imagery</td>
</tr>
<tr>
<td>Stringed instruments</td>
<td>Pedagogical values</td>
</tr>
<tr>
<td>Sol Feige</td>
<td>Evidence to assist with assessment (diagnosis / prognosis)</td>
</tr>
</tbody>
</table>
Session 13  10th November 2011

Objectives / teaching points / recommendations:

• Not specified.

Absent: Harriet.

Researcher reflection: Only the Grade 6 students attended this session as the Grade 5 children had a guest speaker come for a Sex Education class. It was quite productive having a smaller group.

I ended up having additional sessions with two of the Grade 5 children on Monday 14th and one Grade 5 student on Wednesday 16th.

Session 14   17th November 2011

Objectives / teaching points / recommendations:

• “Electromagnetic fields” - Imagery required to commence an electric motor.
• “Molecular naming conventions” - Highlight colour. Preview of voice-over track draft.
• “Satellites” - Uplinks and downlinks. Suggest black background.
• “Solar panels” - I didn't see this student today as he was absent. My own understanding of photovoltaic cells firmed up when I learnt to look at the NP junction as it functions rather than the component parts. Based on this perspective, a more interesting topic could describe the efficiency and inherent limitations of the cell with the revised title “Solar cell efficiency”.
• “Sol feige” - Work on windows.
• “Stadium design” - Suggest using the Pong imagery first and then concluding with Newton’s cradle.
• “Stringed instruments” - Record modulating pitch using the retro, analogue Sruti box which a parent lent to me. Decide on highlight colours, title fonts and other colours.

Absent: Harriet, Sunny.
Researcher reflection: 50% of the final voice-over scripts have now been recorded.

Session 15  1st December 2011

Objectives / teaching points / recommendations:

• “How does hair grow?” - additional questions about variables such as colour and texture.
• “Satellites” – Mention geosynchronous orbit (i.e., the way a satellite maintains its position) and decide if this needs to be included?

Researcher reflection: Today we discussed the creation of “b” files (i.e., expanded versions of the PowerPoint where I edit content and “Save as” the original name with a “b” for Brendan suffix.

Session 16  8th December 2011

Objectives / teaching points / recommendations:

• I timetabled three Storyboard sessions as this was the last week before the Debriefing session.
• Tuesday: “Solar cell efficiency”.
• Wednesday: “How does hair grow?”, “Electromagnetic fields” and “Sol Feige”.
• Thursday: “Molecular naming conventions”, “Satellites”, “Stadium design” and “Stringed instruments”.

Researcher reflection: My attempt to ensure that we had all of the necessary imagery for each animation resulted in the creation of a table matching the voice-over script with imagery. This became known as a “voice-over script / imagery table”.
Session 17  15th December 2011

Objectives / teaching points / recommendations:

• Debriefing session

Absent: Harriet, Ryan.

Researcher reflection: I realise now that there was no way I could have conducted interviews during this one-hour debriefing session and still had time to record the final directors’ commentaries. This became apparent almost immediately so we were able to continue filming the debriefing session while children wrote what they might say for their directors’ commentaries in dot points.

Harriet and Ryan were absent so I rescheduled an additional debriefing session for them on 22nd December 2011.
### Appendix F: Locating the twelve data sources

<table>
<thead>
<tr>
<th>Data source</th>
<th>Hard copy thesis</th>
<th>Web site or CD-ROM</th>
<th>Web site or CD-ROM</th>
<th>Web site or CD-ROM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior knowledge videos</td>
<td>Individual portraits in Chapter 4 (text only)</td>
<td>Row 1 (video and transcript)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Imagery files</td>
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<td>Column 1 (all imagery is embedded in the PowerPoint files)</td>
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<tr>
<td>Voice-over scripts</td>
<td>Individual portraits in Chapter 4 (text only)</td>
<td>Row 2 (video and transcript of final voice-over script)</td>
<td>Column 3 (all voice-over scripts)</td>
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<tr>
<td>Completed explanatory animations</td>
<td>Individual portraits in Chapter 4 (text only)</td>
<td>Row 2 (video and transcript)</td>
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<td></td>
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<tr>
<td>Director's commentaries</td>
<td>Individual portraits in Chapter 4 (text only)</td>
<td>Row 3 (video and transcript)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Student weekly reflections</td>
<td></td>
<td>Column 1 (audio) Column 2 (transcript)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attendance roll</td>
<td>Appendix D</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Lessons plans</td>
<td>Appendix E</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Researcher reflections in weekly reviews</td>
<td></td>
<td>Column 4</td>
<td></td>
<td></td>
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<tr>
<td>Researcher's reflexive journal</td>
<td></td>
<td></td>
<td></td>
<td>All journal entries</td>
</tr>
<tr>
<td>Conceptual consolidation rubrics</td>
<td>Individual portraits in Chapter 4 (final rubric only)</td>
<td>Column 5 (all rubrics)</td>
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<td></td>
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<tr>
<td>Debriefing sessions</td>
<td></td>
<td></td>
<td></td>
<td>Sessions 1A, 1B, 1C and session 2 (videos and transcripts)</td>
</tr>
</tbody>
</table>